METRIC CONVERSION MANUAL

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METRIC CONVERSION MANUAL

MAY 1994

Montana Department of Transportation

PREFACE/INTRODUCTION

CHAPTER 1: METRIC UNITS TERMS,SYMBOLS & CONVERSION FACTORS

CHAPTER 2: RIGHT-OF WAY

CHAPTER 3: ROADWAY DESIGN

CHAPTER 4: STRUCTURES

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Preface

The United States must commit to metrication. Two overwhelming factors, the adoption of the metric system by the remainder of the world and the changing global economy, mandate that this nation must change.

This Guide has been written to provide an explanation of the need for the change, and to serve as a resource to help bridge the gap between building roads in the English-based system of units and the Metric system. It is intended that this guide be used as a reference manual for MDT employees in all areas. Any area which has not been addressed within this manual, but has been affected by the metric conversion may be included in this manual by contacting the MDT Metric Coordinator or Metric Committee.

The AASHTO Metric Task Force requested that each AASHTO Highway Subcommittee and task force develop a position and recommendations addressing metrication items in their area of responsibility.

The AASHTO committees and task forces are attempting to address the metrication impacts in all areas of highway transportation. It is possible that different task forces will adopt different criteria for the same items. It may be that as the highway industry begins to use the criteria, they may be revised. Thus, some metric criteria in this guide may require change at a later date.

While every effort has been made to incorporate the latest data into this manual, the reader is advised to seek the most recent version of AASHTO policy on these issues. Please forward any suggestions for revision to the MDT Metric Coordinator.

Introduction

The United States is converting its transportation system to the metric system, and the date that the Federal Highway Administration has established is September 30, 1996. After that date, no highway projects may be paid for with Federal Lands Highway or Federal-aid Highway funds unless the plans, specifications and estimate (PS&E) are all in metric units.

LEGAL BASIS FOR HIGHWAY CONVERSION

Metric Conversion Act of 1975 & Omnibus Trade and Competitiveness Act of 1988

The impetus for the change came from Congress. *The Metric Conversion Act of 1975* encouraged metrication, but left it as a voluntary activity. As a consequence, virtually no metrication took place. The *Omnibus Trade and Competitiveness Act of 1988* amended the 1975 Act to designate the modern metric system (System International or SI) as the preferred system of weights and measures for U.S. trade and commerce. It also requires each federal agency to convert to metric, and requires each federal agency to use metric in its procurements, grants, and other business-related activities to the extent economically feasible.

These acts did not mandate that individual states, cities, counties, industries, or other organizations convert to metric. However, these entities cannot obtain federal roadway money unless they use metric. It is probable that all will convert to metric to remain eligible for road funds, and it is best that we all convert quickly using consensus guidelines.

Executive Order 12770

In addition to the congressional legislation, Executive Order 12770 was issued in July 1991. It required each federal agency to adopt a metric conversion plan by November 30, 1991. Among the other provisions of the executive order were instructions that the Department of Commerce was to lead the metrication effort.

The Federal Highway Administration Metric Transition Plan was approved by the Secretary of Transportation in October 1991. It laid out procedures and administrative policies for the conversion, and established certain milestone dates. For example, after September 30, 1992, FHWA publications and correspondence were to use metric as the primary system of units for all measurements. FHWA manuals and documents were to be systematically revised and republished in metric so they would be available to guide the conversion. The key date is September 30, 1996. All construction advertised for bids after that date must contain only metric measurements for any federal lands highway or federal-aid highway construction project.

U.S. DOT Metric Conversion Planning Guidelines

On May 8, 1990, the U.S. Department of Transportation (U.S. DOT) issued Order 1020.1C which established policy and administrative procedures for the transition. A change to the order was published in January of 1991. It was further amended and issued as Order 1020.1D on March 23, 1992. The Order defines SI as the official metric system, and refers to ASTM E 380 and several other industry standards and documents for guidance on conversion from U.S. units to SI.

The U.S. DOT order requires agencies to develop plans for conversion to SI to the extent practical. These plans are to include specific dates for changeover to SI in procurements, grants and other business-related activities. U.S. DOT is to participate in the Interagency Committee on Metric Policy, and a U.S. DOT Metric Coordination Committee was created. The Order also contains guidance to U.S. DOT agencies to assist them in completing their conversion plans.

The U.S. DOT Metric Coordinator indicated in early 1992, "It is now the policy of the department to pursue and promote an orderly changeover to the SI system." He also noted that there were nine comprehensive metric conversion plans in place for the nine U.S. DOT agencies, including the Federal Highway Administration (FHWA).

NECESSITY FOR CONVERSION

As of 1990, there were only three nations that had not converted to metric: Burma, Liberia, and the United States. Subsequently, these three nations face serious difficulties in exchanging information with other nations in performing engineering or construction work with other countries.

The current global economy presents serious difficulty. At the end of World War II, the United States was the center of world commerce. At that time, America produced 75% of the world's products; today that value has shrunk to 25%. The world economy has changed rapidly, and industry in the United States is being placed at an increasing disadvantage because of its non-metric system of measurements. American firms are sometimes excluded from doing international business when unable to measure goods in metric terms. A few facts will help put this into perspective:

- The European Community (EC) is composed of 12 nations and is potentially the world's most powerful market, surpassing the United States. The EC specified that products with non-metric labels will not be permitted for sale after 1992.

- The largest U.S. trading partners, Canada and Mexico, are predominantly metric countries.

- Japan has identified the non-metric nature of U.S. products as a specific barrier to the importation of U.S. goods.

BENEFITS OF METRIC CONVERSION

International Acceptance

Metric is the world's measurement language. Fewer and fewer cultures are familiar with U.S. measurement units, and many are increasingly unwilling to overcome this hurdle in order to purchase and utilize American goods. The costs associated with doing business in this country (labor, taxes, tariffs, etc.) make it difficult for U.S. firms to produce their goods at prices which are attractive to other nations. They do not need the additional handicaps of non-standard sizes and a measurement system which is the exception rather than the rule.

International Competitiveness

Greater industrial efficiency and international competitiveness are available through the metric system. Canada has already converted to metric. The Canadian Metric Association reported that the metric system produced direct benefits in terms of reduction in design costs and times, increased construction efficiencies, and improved material and component dimensioning techniques.

Private Sector Conversions Already Underway

Some U.S. businesses have already converted. One of the earliest industries to be affected by metrics was the automobile manufacturing sector. General Motors made an early decision that it must convert its manufacturing. Surprisingly, total conversion costs for GM were less than 1% of their original estimates. IBM and Otis Elevator are other examples of firms that have switched to metric, in this case to increase international competitiveness and to reduce their parts inventories. The wood industry has converted to metric for international sales. Timber products are being shipped overseas in metric sizes.

Opportunity to Consolidate or Redesign

The conversion process allows industries an opportunity to rethink their designs and to incorporate efficient practices. One way to do this is to designate fewer product sizes, reducing inventories and eliminating some manufacturing equipment. Rationalization of fastener sizes during metric conversion allowed IBM to reduce its number of fasteners from 30,000 to 4,000. The liquor industry reduced the number of container sizes from 53 to 7 during its metric conversion.

International Market for Engineering Services

Many American design and construction firms have already begun using metric units for their foreign work. Foreign billings for American architecture/engineering contracting firms amounted to $3.2 billion in 1989, a substantial amount of business.

Simplicity

Perhaps the strongest argument in favor of the metric system is its simplicity of use. It is completely decimal based. There is no need to convert from one type of measurement to another type of measurement. For example, inches do not have to be converted to feet. Feet do not have to be converted to miles. Tablespoons do not have to be converted to cups. There is no requirement to change 27 feet, 8¼ inches into the equivalent number of yards.

The universal experience of every country that has converted has been that the metric system was easier to learn and easier to use than the convoluted system currently being used in the United States. It is just getting the transition underway that is hard. Once the mental leap has been made, calculations are much, much easier.

One Unit for Each Property

One of the greatest advantages is that there is only one unit for measuring each physical property. For example, pressure may be measured by psi, psf, kips/sf, inches of mercury or other units in the conventional U.S. system. The SI system has only one unit for pressure, the pascal. Another example involves power, which may be measured in hp, btu's, watts, and several other terms. In SI, it is measured only in watts. Therefore, metric is a more coherent system in that only one unit is used for each physical quantity and there are no conversion factors to remember.

Conclusion

Metric's coherency, its simple base units, and its use of decimal arithmetic make it an especially logical and useful measurement system.

The American construction community is able to meet the metric conversion challenge in federal construction, and it is in our long-term strategic interest to do so.

There will be initial effort involved. Firm resolve, close cooperation between the public and private sectors, and creative application of our extensive talent and expertise will allow the challenge to be successfully met.

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CHAPTER ONE

Metric Units, Terms, Symbols, and Conversion Factors

BASIC METRIC

Base Units

There are seven metric base units of measurement, six of which are used in design and construction. (The seventh, mole, is the amount of molecular substance and is used in physics.)

Quantity	Unit	Symbol
length	meter	m
mass*	kilogram	kg
time	second	s
electric current	ampere	A
temperature	kelvin	K
luminous intensity	candela	cd

*"Weight" in common practice often is used to mean "mass".

Celsius temperature (°C) is more commonly used than kelvin (K), but both have the same temperature gradients. Celsius temperature is simply 273.15 degrees warmer than kelvin, which begins at absolute zero. For instance, water freezes at 273.15 K and at 0°C, while it boils at 373.15 K and at 100°C. To convert to kelvin from celsius add 273.15.

Decimal Prefixes

Only two decimal prefixes are commonly used with the base units in design and construction:

Prefix	Symbol	Order of Magnitude	Expression
kilo	k	10^3	1000 (one thousand)
milli	m	10^{-3}	0.001 (one thousandth)

The mega (M) for one million (10^6), giga (G) for one billion (10^9), micro (μ) for one millionth (10^{-6}), and nano (n) for one billionth (10^{-9}) are used in some engineering calculations.

Decimal prefixes to the tertiary power of 10 are preferred. The prefixes deci (d) for one tenth (10^{-1}), centi (c) for one hundredth (10^{-2}), deca (da) for ten (10^1), and hecto (h) for one hundred (10^2) have limited application in construction.

Plane and Solid Angles

The radian (rad) and steradian (sr) denote plane and solid angles. They are used in lighting work and in various engineering calculations. In surveying, the units degree (°), minute (′), and second (″) continue in use, with increasing amounts of surveying and design work being done on decimal parts of degrees.

Derived Units

Fifteen derived units with special names are used in engineering calculations:

Quantity	Name	Symbol	Expression
frequency	hertz	Hz	$Hz = s^{-1}$
force	newton	N	$N = kg \cdot m/s^2$
pressure, stress	pascal	Pa	$Pa = N/m^2$
energy, work, quantity of heat	joule	J	$J = N \cdot m$
power, radiant flux	watt	W	$W = J/s$
electric charge, quantity	coulomb	C	$C = A \cdot s$
electric potential	volt	V	V = W/A or J/C
capacitance	farad	F	F = C/V
electric resistance	ohm	Ω	Ω = V/A
electric conductance	siemens	S	S = A/V or Ω^{-1}
magnetic flux	weber	Wb	$Wb = V \cdot s$
magnetic flux density	tesla	T	$T = Wb/m^2$
inductance	henry	H	H = Wb/A
luminous flux	lumen	lm	$lm = cd \cdot sr$
illuminance	lux	lx	$lx = lm/m^2$

Liter, Hectare, and Metric Ton

The liter (L) is the measurement for liquid volume. The hectare (ha) is a metric measurement used in surveying. The metric ton (t) is used to denote large loads such as those used in excavating.

Pronunciation

candela	Accent the second syllable, can-**dell**-ah.
hectare	Accent the first syllable, **heck**-tare. The second syllable rhymes with **care**.
joule	Rhymes with **pool**.
kilometer	Accent the first syllable: **kill**-o-meter.
pascal	Rhymes with **rascal**.
siemens	Sounds like **seamen's**.

Rules for Writing Symbols and Names

- Print unit symbols in upright type and in lower case except for liter (L) or unless the unit name is derived from a proper name.
- Print unit names in lower case, even those derived from a proper name.
- Print decimal prefixes in lower case for magnitudes 10^3 and lower (i.e. k, m, μ, and n) and print the prefixes in upper case for magnitudes 10^6 and higher (i.e. M and G).
- Leave a space between a numeral and a symbol (write 45 kg or 45kg). The exception to this rule is temperature (write 37°C not 37 °C or 37° C).
- Do not use a degree mark (°) with kelvin temperature (write K, not °K).
- Do not leave a space between a unit symbol and its decimal prefix (write kg, not k g).
- Do not use the plural of unit symbols (write 45 kg, not 45 kgs), but do use the plural of written unit names (several kilograms).
- For technical writing, use symbols in conjunction with numerals (the area is 10 m^2); write out unit names if numerals are not used (carpet is measured in square meters). Numerals may be combined with written unit names in nontechnical writing (10 meters).
- Indicate the product of two or more units in symbolic form by using a dot positioned above the line ($kg \cdot m/s^2$).
- Do not mix names and symbols (write N·m or newton meter, not N·meter or newton·m).
- Do not use a period after a symbol (write 12 g, not 12 g.) except when it occurs at the end of a sentence.
- Where modules are used, the recommended basic module is 100 mm, which is similar to the 4-inch module used in building construction (4 inches = 101.6 mm).

UNITS USED ON DRAWINGS

- Label all dimensions on all drawings unless an explanatory note is used (i.e., "All dimensions are shown in millimeters" or "All dimensions are shown in meters"). It is good design practice to label all elevations, dimensions, etc., with the proper units particularly during the interim conversion period.

Rules for Writing Numbers

- Always use decimals, not fractions (write 0.75 g, not ¾ g).
- Use a zero before the decimal marker for values less than one (write 0.45 g, not .45 g).
- Use spaces instead of commas to separate blocks of three digits for any number over four digits (write 45 138 kg or 0.004 46 kg or 4371 kg). Note that this does not apply to the expression of amounts of money.
- In the United States, the decimal marker is a period; in other countries a comma usually is used.

Conversion and Rounding

- When converting numbers from English to metric, generally round the metric value to the same number of digits as there were in the English number (11 miles at 1.609 km/mi equals 17.699 km, which rounds to 18 km).
- Convert mixed English units (feet and inches, pounds and ounces) to the smaller English unit before converting to metric and rounding (10 feet, 3 inches = 123 inches; 123 inches x 25.4 mm/in = 3124.2 mm; round to 3124 mm).
- In a "soft" conversion, an English measurement is mathematically converted to its exact (or nearly exact) metric equivalent. With "hard" conversion, a new rounded, rationalized metric number is created that is convenient to work with and remember.

Soft Metric

- Soft Metric means "No Physical Change". This implies the product in question will not be physically modified to be used in a metric project.
- All that is required is that the product literature and engineering data on these products be available with metric dimensions. It is acceptable if product literature contains both metric and English dimensions. Since product literature costs can be substantial, firms without metric product literature need only develop a supplement to their existing literature. Supplements will be accepted as submittals for an interim period.
- There is no problem with competitive availability of soft converted products on a metric project, since these same products are competitively available today.
- In the future, as standard international metric product sizes are developed by ISO (International Standard Organization) or another standards organization, these products may undergo modification to be compatible in the world market.

Hard Metric

- Hard Metric means "Product Requires Physical Change." The product in question must be physically modified in order to be efficiently utilized in a metric project, which is planned on a metric grid.

- A handful of currently used construction products must undergo hard conversion to new metric sizes.

Visualizing Metric

- One millimeter is about 1/25 inch or slightly less than the thickness of a dime. One meter is the length of a yardstick plus about 3⅓ inches.
  One gram is about the mass (weight) of a large paper clip.
  One kilogram is about the mass (weight) of a softbound model building code book (2.2 pounds).
  One liter is about the volume of a 4-inch cube (100 mm x 100 mm x 100 mm). One liter of water has a mass of 1 kilogram.

- One inch is just a fraction (1/64-inch) longer than 25 mm (1 inch = 25.4 mm; 25 mm = 63/64-inch).
  Four inches are about 1/16 inch longer than 100 mm (4 inches = 101.6 mm; 100 mm = 3-15/16 inches).
  One foot is about 3/16 inch longer than 300 mm (12 inches = 304.8 mm; 300 mm = 11-13/16 inches).
  Four feet are about ¾-inch longer than 1200 mm (4 feet = 1219.2 mm; 1200 mm = 3 feet, 11 ¼ inches).

- The metric equivalent of a typical 2-foot by 4-foot ceiling grid is 600 x 1200 mm, so metric ceiling tiles and lighting fixtures are about 3/8-inch smaller in one dimension and ¾-inch smaller in the other dimension.

- Similarly, the metric equivalent of a 4 by 8 sheet of plywood or drywall is 1200 x 2400 mm, so metric sheets are about ¾-inch narrower and 1½ inches shorter.

- "Rounding down" from multiples of 4 inches to multiples of 100 mm makes dimensions exactly 1.6 percent smaller and areas about 3.2 percent smaller. About 3/16-inch is lost in every linear foot.

Conversion

- Wherever possible, convert measurements to rounded, rationalized "hard" metric numbers. For instance, if anchor bolts are to be embedded to a depth of 10 inches, the exact converted length of 254 mm might be rounded to either 250 mm (9.84 inches) or 260 mm (10.24 inches). The less critical the number, the "rounder" it can be, but ensure that allowable tolerances or safety factors are not exceeded. **When in doubt, stick with the exact "soft" conversion.**

- Round to "preferred" metric numbers. While the preferred numbers for the " 1 foot = 12 inches" system are, in order of preference, those divisible by 12, 6, 4, 3, 2 and 1, preferred metric numbers are, in order of preference, those divisible by 10, 5, 2 and 1 or decimal multiples thereof.

- Use hand calculators or software conversion programs that convert English units to metric. They are readily available and are indispensable to the conversion process. Simply check with any store or catalogue source that sells calculators or software.

- Be careful with the decimal marker when converting areas and volumes; metric numbers can be significantly larger than English numbers (a cubic meter, for instance, is one billion cubic millimeters).

LENGTH, AREA, AND VOLUME

One metric unit is used to measure length, area, and volume in most design and construction work:

- meter (m).

Rules for Linear Measurement (Length)

- Use only the meter and millimeter in building design and construction.
- Use the meter or kilometer for long distances and the micrometer for precision measurements.
- Do not use the centimeter.
- For survey measurement, use the meter and the kilometer.

Rules for Area

- The square meter is preferred.
- Very large areas may be expressed in square kilometers and very small areas, in square millimeters.
- Use the hectare (10 000 square meters) for land and water measurement only.
- Do not use the square centimeter.
- Linear dimensions such as 40 x 90 mm may be used; if so, indicate width first and height second.

Rules for Volume and Fluid Capacity

- Cubic meter is preferred for volumes in construction and for large storage tanks.
- Use liter (L) and milliliter (mL) for fluid capacity (liquid volume). One liter is 0.001 of a cubic meter or 1000 cubic centimeters.
- Since a cubic meter equals one billion cubic millimeters, the cubic decimeter and cubic centimeter may be used in limited applications, since they are multiples of 1000 in volume measurement.

Area, Length, and Volume Conversion Factors

Quantity	From English Units	To Metric Units	Multiply By
Length	mile	km	1.609 344
	yard	m	0.914 4
	foot	m	0.304 8
	foot	mm	304.8
	inch	mm	25.4
Area	square mile	km^2	2.590
	acre	m^2	4 046.856
	acre	ha (10 000 m^2)	0.404 685 6
	square yard	m^2	0.836 127 36
	square foot	m^2	0.092 903 04
	square foot	ha (10 000 m^2)	0.000 009 29
	square inch	mm^2	645.16
Volume	acre foot	m^3	1 233.49
	cubic yard	m^3	0.764 555
	cubic foot	m^3	0.028 316 8
	cubic foot	cm^3	28 316.85
	cubic foot	L (1000 cm^3)	28.316 85
	100 board feet	m^3	0.235 974
	gallon	L (1000 cm^3)	3.785 41
	1000 gallons	kL (1000 L)	3.785 41
	cubic inch	cm^3	16.387 064
	cubic inch	mm^3	16 387.064

NOTE: Underline denotes exact number

CIVIL AND STRUCTURAL ENGINEERING

The metric units used in civil and structural engineering are:

- meter (m)
- kilogram (kg)
- second (s)
- newton (N)
- Pascal (Pa)

Rules for Civil and Structural Engineering

- There are separate units for mass and force.
- The kilogram (kg) is the base unit for mass, which is the unit quantity of matter independent of gravity.
- The newton (N) is the derived unit for force (mass times acceleration, or $kg \cdot m/s^2$). It replaces the unit "kilogram-force" (kgf), which should not be used.
- Do not use the joule to designate torque, always use newton-meter ($N \cdot m$).
- The pascal (Pa) is the unit for pressure and stress. The term "bar" is not a metric unit and should not be used.
- Structural calculations should be shown in MPa or kPa.
- Plane angles in surveying (cartography) will continue to be measured in degrees (either decimal degrees or degrees, minutes, and seconds) rather than the metric radian.
- Slope is expressed in non-dimensional ratios. The horizontal component is shown first and then the vertical. For instance, a rise of one meter in four meters is expressed as 4:1. The units that are compared should be the same (meters to meters, millimeters to millimeters).

Note: The SI standard is to express slope as rise over run.
The MDT will continue to use the run over rise convention as explained above.

Civil and Structural Engineering Conversion Factors

Quantity	From English Units	To Metric Units	Multiply By
Mass	lb kip (1000 lb)	kg metric ton (1000 kg)	0.453 592 0.453 592
Mass/unit length	plf	kg/m	1.488 16
Mass/unit area	psf	kg/m^2	4.882 43
Mass density	pcf	kg/m^3	16.018 5
Force	lb kip	N kN	4.448 22 4.448 22
Force/unit length	plf klf	N/m kN/m	14.593 9 14.593 9
Pressure, stress, modulus of elasticity	psf ksf psi ksi	Pa kPa kPa MPa	47.880 3 47.880 3 6.894 76 6.894 76
Bending moment, torque, moment of force	ft-lb ft-kip	N·m kN·m	1.355 82 1.355 82
Moment of mass	lb-ft	kg·m	0.138 255
Moment of inertia	$lb\text{-}ft^2$	$kg \cdot m^2$	0.042 140 1
Second moment of area	in^4 ft^4	mm^4 m^4	416 231 0.008 63
Section modulus	in^3	mm^3	<u>16 387.064</u>

NOTE: Underline denotes exact number.

METRIC PROJECT DEFINITION

A project is "metric" when:

- Specifications show SI units only
- Drawings show SI units only
- Construction takes place in SI units only
- Inspection occurs in SI units only
- Cost estimating is based on SI units only

This does not imply that construction products must change. Over 95% of the products used in construction today will undergo no physical change at all during the metric transition. All that will occur is that the dimensions of the product will be identified in drawings, specifications, and on product literature in metric units, a process called soft conversion.

There are a handful of products that must undergo a physical change now in order to be efficiently used in metric construction. This process is called hard conversion. As international standards are developed for more products, American products will then be hard converted to those sizes, to enhance their export potential.

Dual Dimensions

Dual dimensions **shall not** be used on metric projects.

Dual dimension example: 102 mm (4 inches)

Dual dimensioning is a wasted effort. It has no effect in construction documents. When English measurements are present, readers will use them and will ignore the metric measurement.

An exact analogy is appliance directions given in English and French. Most English-speaking people will ignore the French instructions, and vice versa.

Note: Dual dimensions may be used on some right-of-way drawings when previously recorded English values are referenced.

Summary

It is most important that drawings and specifications be metric exclusively. It is of secondary importance if measurements are hard or soft metric.

When documents contain SI measurement only, the reader will learn metric in order to execute the work.

GRANT BINDER
800 298 5555

CHAPTER TWO

Right-of-Way Bureau Guidelines

1. Introduction

The following guidelines identify the method and procedures for metric conversion in the R/W Bureau. The Preconstruction Bureau develops the base map for our various R/W plans.

We will follow the suggested guideline to show some dual dimensions on the R/W, Utility, and Railroad plans and deed exhibits. Dual measurements will be shown for recorded distances and metrics only will be shown for new measurements. Areas will be shown in both metric and English.

2. Implementation

When a project is identified with the centerline in metrics R/W guidelines for metrics will be used. Projects now being worked on may be converted to metric measurements if the Preconstruction Bureau changes the centerline to metrics. If a project has already been authorized for acquisition using a non-metric centerline the R/W plans are not to be revised to metrics.

3. Plan Preparation

a. Design - New widths of R/W will be set in increments of five meters (i.e. - 20, 25, 30, etc.). It is preferred that this measurement is to be measured from the centerline, but may be an additional distance from the existing roadway or property line.

- Collector Routes - The minimum standard total width of R/W will be 20 m on each side of the centerline.

- Arterial Routes - The minimum standard total width of R/W will be 25 m on each side of the centerline.

Existing right-of-way widths will be shown in meters rounded to two decimal places.

b. Scale - The bar scale in metrics will be shown on each sheet. (OPTION: The English measurement may also be shown on the bar scale.)

- R/W Plan sheets will generally be shown for:
  rural area on a scale of 1:1000
  urban area on a scale of 1:500

- Ownership maps will generally be shown on a scale of 1:5000

- R/W exhibits will generally be shown to the same scale or half scale of the R/W plan sheets.

c. Plan sheet size - Currently our plan sheets are 558.8 mm (22") by 914.4 mm (36"). We will continue with this current overall paper size since we have it in stock until

official metric sized sheets are acquired. We will adjust the inside borders to set the drawing area boundaries to metric dimensions as described in the first portion of Chapter 3.

d. Existing roadways - The total width of the existing roadway right-of-way will be shown in meters with the English measurement shown in parenthesis.

e. Other standards -

- The degree of curve will no longer be used. All horizontal curve data will be based on the radius in meters.

- Spiral curves - Chords rather than concentric curves will be used to describe proposed R/W where a spiral curve transition is used.

f. Coordinates -
Coordinates and calculations will follow the criteria identified in the Roadway Design Section (Chapter 3, Page 12).

4. **Property descriptions and Deed Exhibits** - Each deed exhibit and property description will follow the same procedures as for the R/W plans. Recorded distances will be shown in metrics with the English measurements shown in parenthesis. New measurements will only be shown in metrics. The written portion of the deed will also show dual measurements using the same guidelines. All areas will generally be shown in both measurements.

a. Exhibit size - On metric projects each exhibit will be prepared on paper 297 mm (11.7") by 420 mm (16.5"). However, we will continue to use the standard paper on hand until the metric standard paper will be available. Some exhibits may still be prepared on existing paper in stock to match the other exhibits already completed for the same project. The exhibits generated from the CADD on the new projects will be an exact 50% reduction of the full sized R/W plan sheet. This will allow it to be scaled without using special factors.

b. Angular measurements shall continue to be shown in degrees, minutes, and seconds.

c. Areas shall be given in both metric and English.

d. Exceptions - R/W professionals shall reserve the right to redraft any drawings in English units for the purpose of any public presentations and/or court proceedings.

5. **Appraisals and Negotiations** - Each of the forms and reports used in the appraisals and negotiations will be shown in metric measurements with the English measurement in parenthesis.

a. Land Owners - Both metric and English measurements will be shown in the appraisal reports, agreements and documents.

b. Handouts - Special handouts will be available to distribute to each land owner and interested person explaining the metric system and a brief picture diagram of the size difference between metric and English measurements. Each person compensated should receive a copy. This will be developed in cooperation with the Public Affairs Bureau. See Chapter 12 for more information.

6. **Utilities** - Utility and Railroad plans will be prepared using metric measurements with the English also shown in parenthesis. Agreements will be prepared using metric measurements with English in parenthesis.

7. **Accuracy** - This identifies the rounding procedure to be followed. For extreme accuracy use the conversion factors below:

   a. Meter - This should be shown as a whole number unless it is necessary to use a soft conversion from feet. In this case the meter should be shown to the closest 0.01 m.

   b. Square meter - This should also be shown as a whole number (1 m^2) unless it is necessary to use a soft conversion from square feet. In this case the square meter should be shown to the closest 0.01 m^2.

   c. Hectares - This should be shown out to 0.001 hectares at all times.

   d. Stationing - All stationing will be shown in metrics. Each 100 meters will constitute one station. It will be shown as 1+00 and should be carried out to two places past the decimal. (i.e. 1+22.45)

   e. Other - Any metric unit which is less than one whole unit should be preceded with a zero. (i.e. 0.22 m)

8. **Examples of calculations**

   a. To convert measurements from English to metric:

Multiply	By	To Obtain
feet	0.304 8	meters
square feet	0.092 903 04	square meters
acres	0.404 685 6	hectares

   b. To convert measurements from metric to English:

Multiply	By	To Obtain
meters	3.280 839 90	feet
square meters	10.763 910 42	square feet
hectares	2.471 054 07	acres

EXAMPLES OF CALCULATIONS AND ROUNDING:

130 feet	X	0.304 8	=	39.62 meters (soft conversion) 40 meters (hard conversion)
2100 square feet	X	0.092 903 04	=	195.10 square meters (soft conversion) 195 square meters (hard conversion)
2.30 acres	X	0.404 685 6	=	0.931 hectares (soft conversion) 0.93 hectares (hard conversion)

EXAMPLES OF CALCULATIONS AND ROUNDING (Cont.)

25 meters	X	3.280 839 90	=	82.02 feet (soft conversion) 82 feet (hard conversion)
214.61 sq. meters	X	10.763 910 42	=	2310.04 square feet (soft conversion) 2310 square feet (hard conversion)
0.661 hectares	X	2.471 054 07	=	1.63 acres (soft conversion) 1.63 acres (hard conversion)

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CHAPTER THREE

Roadway Design

The AASHTO Task Force on Geometric Design has reviewed the *Policy on Geometric Design of Highways and Streets* (the "Green Book"). It identified nine areas critical to basic geometric design, and submitted initial recommendations addressing metrication items in Geometric Design to the AASHTO Standing Committee on Highways. The committee's recommendations have since been approved by AASHTO.

These values can be used by MDT as interim design criteria until a complete version of *A Policy on Geometric Design of Highways and Streets* (the "Green Book") is published in 1995.

DRAWING SIZES

The ISO "A" series drawing sizes are preferred metric sizes for design drawings. There are five "A" series sizes:

ISO Designation	Metric Sheet Size	Replaces	Current MDT Sizes
A0	841 x 1189 mm	34 x 44 inches	--
A1	594 x 841 mm	22 x 34 inches	559 mm x 864 mm (D)
A2	420 x 594 mm	17 x 22 inches	--
A3	297 x 420 mm	11 x 17 inches	279 mm x 432 mm (B)
A4	210 x 297 mm	8½ x 11 inches	216 mm x 279 mm (A)

Sheet size "A0" is the base drawing with an area of one square meter. Smaller sizes are obtained by halving the long dimension of the previous size. All "A" size have a height to width ratio of one to the square root of two.

All full-sized plan sheets should conform to the "A1" metric series size. Existing size D paper will be used until metric paper is available. Drawing borders of 13 mm will be used at the top and bottom and 13 mm at the right edge. The left border (binding edge) will be 51 mm. The 2.9" excess width should be added to the left (binding edge) border of size D paper.

When metric paper becomes available, drawings shall conform to the guidelines in Chapter 4 of the Road Design Manual.

DRAWING SCALES

Metric drawing scales are expressed in non-dimensional ratios. Nine scales are preferred: 1:1 (full size), 1:5, 1:10, 1:20, 1:50, 1:100, 1:200, 1:500, and 1:1000. Three others have limited usage: 1:2, 1:25, and 1:250.

Drawing Usage	Metric Scales		English Scales	Percent Enlargement or Reduction Using Metric Scale
	Preferred	Other		
Strip Maps	1:1		Full size	No change
		1:2	Half size	No change
	1:5		1" = ¼' 1" = ⅓'	-40% -20%
	1:10		1" = 1'	+20%
	1:20		1" = 2'	+20%
		1:25	1" = 2'	-4%
Typical Section	1:50		1" = 5'	+20%
Cross Sections[1]	1:100		1" = 10'	+20%
Cross Sections[1] and Details	1:200		1" = 20'	+20%
Details		1:250	1" = 20'	-4%
Plan & Profile[2] (Urban)	1:500		1" = 30' 1" = 40' 1" = 50'	-28% -4% +20%
Plan & Profile[2] (Rural)	1:1000		1" = 60' 1" = 100'	-28% +20%

[1]The vertical scale will be a 1:1 proportion of the horizontal scale.
[2]The vertical scale will be a 1:10 proportion of the horizontal scale.

ELEVATION AND CONTOUR INTERVALS

Benchmark elevations will be directly converted from feet to meters. For example, a benchmark elevation of 639.28 feet will be converted directly to 194.853 meters (639.28 ft. x 0.304 8 m/1 ft. = 194.853 m). Benchmark elevations should be shown to a 0.001 meter accuracy.

When contours are shown on Bridge Layout sheets and other drawings, the contour interval will be 0.5 meters. Each second contour representing an even meter elevation (202.0, 203.0, etc.) will be emphasized and annotated. Intermediate 0.5 meter contours will

not be annotated unless they represent a high or low contour on the ground surface that cannot be determined by interpolations between adjacent full meter contours.

A 0.5 meter contour interval is equivalent to about 1.6 feet. In rugged terrain or on steep slopes, the contour density may interfere with readability. When this occurs, the 0.5 meter contours should be removed from the densely packed areas only. The even meter contours are to be retained in these areas.

Should the user need greater accuracy, Photogrammetry can produce contours at other intervals.

Metric Interval	English Interval
0.5 m	2 ft.
1 m	5 ft.
5 m	10 ft.

STATIONING AND CROSS-SECTIONS

A station concept based on 100 meters (1+00) will be used for metric plans. For example, Station 12+27.39 indicates a point 27.39 m forward of Station 12+00.

Use an equivalent conversion from English to metric when re-establishing points from a previously run survey. For example, P.I. Station 456+35.00 from a 1965 survey using English units would be defined as Station 139+09.55 (45 635 ft. x 0.304 8 m/1 ft = 13 909.55 m) in a metric survey. The 100 meter stationing on new alignments is arbitrary, but is the standard chosen by MDT.

Standard cross-section intervals of 20 meters rural and 10 meters urban should be used where alignment is maintained over existing embankments and through rolling terrain. Although 20 meters should be considered the standard, a larger interval may be considered when uniform templates are used over flat terrain. Additional cross-sections should be provided to reflect abrupt changes in either the template or the existing ground.

The usual horizontal and vertical cross-section scale is 1:100 [Use 1 m - 100 m]; 1:200 is also acceptable, where greater width or height is required.

ANGLES AND HORIZONTAL CURVES

Angular measurement will continue to be expressed in degrees, minutes, and seconds.

Radius definition of curves, in meters, will be used rather than Degree of Curve as we currently use.

For example, a 3 degree horizontal curve on *new alignment* (Radius = 1909.86 ft. or 582.125 meters) should be rounded to a 600 meter radius curve. Metric radius on *paper relocated* horizontal curves should be selected from the recommended radius table on the next page, or if not practical, should be in five-meter increments.

On the other hand, alignments which incorporate a previously defined horizontal curve should continue to express the radius to the closest 0.001 meter. If the three degree curve noted above is a re-creation of a previously established curve, it should be assigned a 582.125 meter radius.

Listed below are three cases defining horizontal curves. In all three cases the curve is defined by the P.I. Station 300+59.41 (English), equivalent to P.I. Station 91+62.11 (metric).

Case A: Normal English curve definition.

Case B: Metric definition assuming that Case A curve data defined the roadway centerline from a previous survey and is to be retained. The radius is a direct conversion from English to metric, rounded to three decimal places. The remaining curve data is obtained by converting the radius to metric and then calculating the desired item to two decimal places.

Case C: Metric definition of a paper relocation starting at P.I. Station 91+62.11 having approximately the same curvature as the Case A curve. Note that the radius was selected from the table shown below.

Case A	Case B	Case C
P.I. Sta. = 300+59.41	P.I. Sta. = 91+62.11	P.I. Sta. = 91+62.11
Δ = 12° 30'	Δ = 12° 30'	Δ = 12° 30'
D = 3° 00'	R = 582.125 m	R = 600 m
T = 209.16'	T = 63.75 m	T = 65.71 m
L = 416.67'	L = 127.00 m	L = 130.90 m

RECOMMENDED CURVE RADII

Select curve radii from the following:

Approximate Degree of Curvature	Metric Radius	Approximate Degree of Curvature	Metric Radius
0°15'	7000 m	4°00'	450 m
0°30'	3500 m	5°00'	350 m
0°45'	2350 m	6°00'	300 m
1°00'	1750 m	7°00'	250 m
1°30'	1150 m	8°00'	220 m
2°00'	900 m	9°00'	190 m
2°30'	700 m	10°00'	170 m
3°00'	600 m	11°00'	160 m
3°30'	500 m	12°00'	150 m

From Chapter 9, MDT Road Design Manual

Circular Curves

SELECTED CURVE FORMULAS

CURVE SYMBOLS		CURVE FORMULA
Δ =	Deflection Angle, degrees	$T = R(\tan(\Delta/2))$
T =	Tangent Distance = distance from PC to PI = distance from P.I. to P.T.	$L = 2\pi R \Delta/360$
L =	Length of curve in meters = distance from P.C. to P.T. along curve	$E = T(\tan \Delta/4)$
R =	Radius of curve in meters	
E =	Mid ordinate = distance from PI to curve	

Note: Additional formulas are available in Chapter 9, MDT Road Design Manual.

The following table gives minimum rounded radii in meters for limiting values of superelevations for various design speeds.

Design Speed (km/h)	Minimum rounded radius in meters
	8% maximum superelevation
30	30
40	55
50	85
60	125
70	180
80	230
90	305
100	395
110	505

Spiral Curves

Spiral Curve Symbols

L_s = Length of spiral.

L_c = Length of circular curve.

T_s = Tangent distance Master PI to TS or ST, or tangent distance of completed curve.

R_c = Radius of the circular curve.

p = Offset distance from the main tangent to the PC or PT of the circular curve produced.

k = Distance from TS to point on main tangent opposite the PC of the circular curve produced.

Δ = Intersection angle between tangents of the entire curve.

Δ_c = Intersection angle between tangents at the SC and the CS or the central angle of the circular curve portion of the curve.

θ_s = Intersection angle between the tangent of the complete curve and the tangent at the SC, the spiral tangents intersection angle.

Spiral Curve Formulas

$\theta_s = {}^{Ls}/_{Rc} \times 28.6479$

$\Delta_c = \Delta - 2\theta_s$

$L_c = (\Delta_c/360) \times 2\pi R$

$T_s = (R_c+p) \tan \Delta/2 + k$

$E_s = (R_c+p)[(1/\cos \Delta/2) - 1] + p$

Note: Additional formulas are available in Chapter 9 of the MDT Road Design Manual.

RATE OF SUPERELEVATION AND MINIMUM LENGTH OF TRANSITION
(Rural Highways and High-Speed Urban Highways)
(Two-Lane, Two-Way Highways)

. e	V = 50 km/h			V = 60 km/h			V = 70 km/h			V = 80 km/h		
	R(m)	Trans. Length		R(m)	Trans. Length		R(m)	Trans. Length		R(m)	Trans. Length	
		L(m)	TR(m)		L(m)	TR(m)		L(m)	TR(m)		L(m)	TR(m)
NC	R≥1090	0	0	R≥1495	0	0	R≥1970	0	0	R≥2440	0	0
0.02	1090>R≥795	30	30.00	1495>R≥1095	35	35.00	1970>R≥1445	40	40.00	2440>R≥1795	45	45.00
0.03	795>R≥500	30	20.00	1095>R≥700	35	23.33	1445>R≥925	40	26.67	1795>R≥1170	45	30.00
0.04	500>R≥350	30	15.00	700>R≥490	35	17.50	925>R≥650	40	20.00	1170>R≥825	45	22.50
0.05	350>R≥260	30	12.00	490>R≥365	35	14.00	650>R≥490	40	16.00	825>R≥620	45	18.00
0.06	260>R≥190	35	11.67	365>R≥270	40	13.33	490>R≥370	40	13.33	620>R≥475	45	15.00
0.07	190>R≥135	40	11.43	270>R≥200	45	12.86	370>R≥275	50	14.29	475>R≥360	55	15.71
0.08	135>R≥85	45	11.25	200>R≥125	50	12.50	275>R≥180	55	13.75	360>R≥230	60	15.00
	R_{min} = 85 m			R_{min} = 125 m			R_{min} = 180 m			R_{min} = 230 m		

Key:

R = Radius of curve

V = Design speed

e = Superelevation rate

e_{max} = 0.08

L = Minimum length of superelevation runoff (from adverse slope removed to full super)

TR = Tangent runout from NC to adverse slope removed

NC = Normal crown

From Chapter 9 of the MDT Road Design Manual.

RATE OF SUPERELEVATION AND MINIMUM LENGTH OF TRANSITION
(Rural Highways and High-Speed Urban Highways)
(Multi-Lane Highways)

e	V = 90 km/h			V = 100 km/h			V = 110 km/h		
	R(m)	Trans. Length		R(m)	Trans. Length		R(m)	Trans. Length	
		L(m)	TR(m)		L(m)	TR(m)		L(m)	TR(m)
NC	R≥2965	0	0	R≥3625	0	0	R≥4180	0	0
0.02	2965>R≥2185	50	50.00	3625>R≥2675	60	60.00	4180>R≥3095	65	65.00
0.03	2185>R≥1400	50	33.33	2675>R≥1750	60	40.00	3095>R≥2000	65	43.33
0.04	1400>R≥1000	50	25.00	1750>R≥1250	60	30.00	2000>R≥1465	65	32.50
0.05	1000>R≥770	60	24.00	1250>R≥950	65	26.00	1465>R≥1140	70	28.00
0.06	770>R≥600	75	25.00	950>R≥750	80	26.67	1140>R≥900	85	28.33
0.07	600>R≥465	85	24.29	750>R≥590	90	25.71	900>R≥735	95	27.14
0.08	465>R≥305	100	25.00	590>R≥395	105	26.25	735>R≥505	110	27.50
	R_{min} = 305 m			R_{min} = 395 m			R_{min} = 505 m		

e_{max} = 0.08

Key:

R = Radius of curve

V = Design speed

e = Superelevation rate

L = Minimum length of superelevation runoff (from adverse slope removed to full super)

TR = Tangent runout from NC to adverse slope removed

NC = Normal crown

From Chapter 9 of the MDT Road Design Manual.

RATE OF SUPERELEVATION AND MINIMUM LENGTH OF TRANSITION
(Rural Highways and High-Speed Urban Highways)
(Multi-Lane Highways)

e	V = 50 km/h			V = 60 km/h			V = 70 km/h			V = 80 km/h		
	R(m)	Trans. Length		R(m)	Trans. Length		R(m)	Trans. Length		R(m)	Trans. Length	
		L(m)	TR(m)		L(m)	TR(m)		L(m)	TR(m)		L(m)	TR(m)
NC	R≥1090	0	0	R≥1495	0	0	R≥1970	0	0	R≥2440	0	0
0.02	1090>R≥795	30	30.00	1495>R≥1095	35	35.00	1970>R≥1445	40	40.00	2440>R≥1795	45	45.00
0.03	795>R≥500	30	20.00	1095>R≥700	35	23.33	1445>R≥925	40	26.67	1795>R≥1170	45	30.00
0.04	500>R≥350	35	17.50	700>R≥490	40	20.00	925>R≥650	40	20.00	1170>R≥825	45	22.50
0.05	350>R≥260	45	18.00	490>R≥365	50	20.00	650>R≥490	50	20.00	825>R≥620	55	22.00
0.06	260>R≥190	55	18.33	365>R≥270	60	20.00	490>R≥370	60	20.00	620>R≥475	65	21.67
0.07	190>R≥135	60	17.14	270>R≥200	65	18.57	370>R≥275	70	20.00	475>R≥360	80	22.86
0.08	135>R≥85	70	17.50	200>R≥125	75	18.75	275>R≥180	80	20.00	360>R≥230	90	22.50
	R_{min} = 85 m			R_{min} = 125 m			R_{min} = 180 m			R_{min} = 230 m		

Key:

R = Radius of curve

V = Design speed

e = Superelevation rate

e_{max} = 0.08

L = Minimum length of superelevation runoff (from adverse slope removed to full super)

TR = Tangent runout from NC to adverse slope removed

NC = Normal crown

From Chapter 9 of the MDT Road Design Manual.

RATE OF SUPERELEVATION AND MINIMUM LENGTH OF TRANSITION
(Rural Highways and High-Speed Urban Highways)
(Two-Lane, Two-Way Highways)

e	V = 90 km/h			V = 100 km/h			V = 110 km/h		
	R(m)	Trans. Length		R(m)	Trans. Length		R(m)	Trans. Length	
		L(m)	TR(m)		L(m)	TR(m)		L(m)	TR(m)
NC	R ≥ 2965	0	0	R ≥ 3625	0	0	R ≥ 4180	0	0
0.02	2965 > R ≥ 2185	50	50.00	3625 > R ≥ 2675	60	60.00	4180 > R ≥ 3095	65	65.00
0.03	2185 > R ≥ 1400	50	33.33	2675 > R ≥ 1750	60	40.00	3095 > R ≥ 2000	65	43.33
0.04	1400 > R ≥ 1000	50	25.00	1750 > R ≥ 1250	60	30.00	2000 > R ≥ 1465	65	32.50
0.05	1000 > R ≥ 770	50	20.00	1250 > R ≥ 950	60	24.00	1465 > R ≥ 1140	65	26.00
0.06	770 > R ≥ 600	50	16.67	950 > R ≥ 750	60	20.00	1140 > R ≥ 900	65	21.67
0.07	600 > R ≥ 465	60	17.14	750 > R ≥ 590	60	17.14	900 > R ≥ 735	65	18.57
0.08	465 > R ≥ 305	65	16.25	590 > R ≥ 395	70	17.50	735 > R ≥ 505	75	18.75
	R_{min} = 305 m			R_{min} = 395 m			R_{min} = 505 m		

e_{max} = 0.08

Key:

R = Radius of curve

V = Design speed

e = Superelevation rate

L = Minimum length of superelevation runoff (from adverse slope removed to full super)

TR = Tangent runout from NC to adverse slope removed

NC = Normal crown

From Chapter 9 of the MDT Road Design Manual.

RATE OF SUPERELEVATION AND MINIMUM LENGTH OF TRANSITION
(Low-Speed Urban Streets)

e	V = 30 km/h					V = 40 km/h					V = 50 km/h				
	R(m)	Trans. Length (Two-Lane)		Trans. Length (Multi-Lane)		R(m)	Trans. Length (Two-Lane)		Trans. Length (Multi-Lane)		R(m)	Trans. Length (Two-Lane)		Trans. Length (Multi-Lane)	
		L(m)	TR(m)	L(m)	TR(m)		L(m)	TR(m)	L(m)	TR(m)		L(m)	TR(m)	L(m)	TR(m)
NC	R≥25	0	0	0	0	R≥55	0	0	0	0	R≥104	0	0	0	0
0.02	25>R≥22	10	10.00	15	15.00	55>R≥47	15	15.00	15	15.00	104>R≥86	15	15.00	15	15.00
0.03	22>R≥21	15	10.00	20	13.33	47>R≥46	15	10.00	20	13.33	86>R≥83	15	10.00	25	16.67
0.04	21>R≥20	15	7.50	25	12.50	46>R≥45	20	10.00	25	12.50	83>R≥80	20	10.00	30	15.00
	R_{min} = 20 m					R_{min} = 45 m					R_{min} = 80 m				

e	V = 60 km/h					V = 70 km/h				
	R(m)	Trans. Length (Two-Lane)		Trans. Length (Multi-Lane)		R(m)	Trans. Length (Two-Lane)		Trans. Length (Multi-Lane)	
		L(m)	TR(m)	L(m)	TR(m)		L(m)	TR(m)	L(m)	TR(m)
NC	R≥178	0	0	0	0	R≥258	0	0	0	0
0.02	178>R≥142	20	20.00	20	20.00	258>R≥204	20	20.00	20	20.00
0.03	142>R≥135	20	13.33	25	16.67	204>R≥193	20	13.33	30	20.00
0.04	135>R≥130	25	12.50	35	17.50	193>R≥185	25	12.50	40	20.00
	R_{min} = 130 m					R_{min} = 185 m				

e_{max} = 0.04

Key:

R = Radius of curve
V = Design speed
e = Superelevation rate
L = Minimum length of superelevation runoff (from adverse slope removed to full super)
TR = Tangent runout from NC to adverse slope removed
NC = Normal crown

From Chapter 9 of the MDT Road Design Manual.

SURVEY PLOTTING ACCURACY

As a frame of reference, distances expressed in metric units will have the following accuracy in English units:

- Closest 0.1 meters will be ± 2" of the true distance.
- Closest 0.01 meters will be ± 3/16" of the true distance.

With this in mind, survey distances and elevations transferred to plan sheets should be shown as follows:

- Horizontal alignment data (curve information, equations, reference point tie-ins, etc.) to the closest 0.01 m. Benchmark elevations should be shown to the closest 0.001 m.
- Roadway elevations, used for pavement tie-ins and vertical clearance computations, should be shown to the closest 0.01 m.

COORDINATES

One exception to the exclusive use of the SI Foot (1 foot = 0.304 8 m) is some coordinate data received from the Photogrammetry and Survey Section. The electronic survey equipment used by the MDT measures distances in meters and then internally converts the distance to feet using the U.S. Survey Foot (1 foot = 0.304 800 61 m) which is slightly different than the SI Foot.

For all practical purposes, the two are the same with approximately two parts per million difference. Where this causes a problem is when metric coordinates are developed using English survey data.

The Photogrammetry and Survey Section will identify the conversion factor used to produce metric coordinates. The designer shall identify the conversion factor used as a footnote to the coordinate table in the plans.

Stationing, bearing and section tie calculations using metric coordinates will need to be performed using the appropriate conversion factor. If there is any question to the appropriate conversion factor, contact the Photogrammetry and Survey Section.

PROPOSED FEATURES ON ROADWAY PLANS

The location of all proposed features should be given in meters or decimal parts of meters to the following accuracy:

- All proposed horizontal alignment data should be given to an accuracy of 0.01 meters.
- New metric curve radii should follow the recommended radii or be in 5-meter increments. Existing curve radii should be rounded to the nearest 0.001 m and used to calculate new curve data.
- New vertical profile alignment data should be shown with V.P.I. Stations at even 10 m stations, V.C. Lengths in 20 m increments, and V.P.I. Elevations given to 0.01 m accuracy, where practical. Existing vertical data should be shown to 0.01 m for stationing and 0.01 m for elevations.

- All other vertical elevations (breaks in ditch grades, pipe invert elevations, etc.) should be shown to the closest 0.01 meters.

- The location of all proposed features should be shown to the closest one meter, where practical, and if needed, to 0.1 or 0.01 meter. The following increments are recommended:

1 Meter	0.1 Meter	0.01 Meter
Approaches	Culverts	W-Beam Guardrail
Earthwork Balance Points	Manholes, Valves	Conc. Barrier Rail
Cattleguards	Fencing	Bridges
Seeding	Curbs, Sidewalk	

Note: W-Beam Guardrail should be in 3.81 m increments and concrete median rail should be in 3.05 m increments.

SPECIFICATIONS

All measurements in construction specifications should be stated in metric. Until existing specification systems are fully converted, the specifier may:

- **Specify metric products** (check to see if the products to be specified are available in metric sizes).

- **Refer to metric or dual unit codes and standards.** ASHRAE, ASME, and ACI, among others, publish metric editions of some standards. Two of the country's three model code groups (BOCA and SBCCI) as well as ASTM and NFPA publish their documents with dual units (both metric and English measurements). In addition, most handicapped accessibility standards and a number of product standards are published with dual units. The metric measurements are virtually exact, "soft" numerical conversions that, over time, will be changed through the consensus process into rationalized, rounded "hard" metric dimensions. For now, use the "soft" metric equivalents.

- **Convert existing unit measurements to metric** (follow conversion rules on Chapter 1).

CROSS SECTION ELEMENTS & DESIGN DATA

The following information is intended to summarize selected design and detailing "equivalent values" as the translation from English to metric units is implemented.

Design Speed

Metric Value (km/h)	English Equivalent (mph)	Running Speed (km/h)
40 (24.85 mph)	25	40
50 (31.07 mph)	30	47
60 (37.28 mph)	35 & 40	55
70 (43.50 mph)	45	63
80 (49.71 mph)	50	70
90 (55.92 mph)	55	77
100 (62.14 mph)	60	85
110 (68.35 mph)	65 & 70	91

Shoulders

Metric Value (m)	English Equivalent (ft.)
0.6 (1.97 ft)	2
1.2 (3.94 ft)	4
1.8 (5.91 ft)	6
2.4 (7.87 ft)	8
3.0 (9.84 ft)	10

The Task Force, in establishing shoulder width values, attempted to recognize the value of a shoulder width less than 1 m and provide flexibility for that instance. Always maintain lane and shoulder widths in 0.1 meter increments.

Lane Width

The values established by the AASHTO Task Force on Geometric Design are slightly narrower (ranging from 4 to 10 percent less) than the corresponding Canadian values. Canadian values are set in 0.25 m increments. This level of precision (hundredths of a meter) appears to be excessive for this element. The Task Force believes that precision to 0.1 m is acceptable and has set values accordingly.

Metric Value (m)	English Equivalent (ft.)	Comparison
2.7 (8.86 ft)	9	(1.56% less than 9 ft. lane)
3.0 (9.84 ft)	10	(1.60% less than 10 ft. lane)
3.3 (10.83 ft)	11	(1.55% less than 11 ft. lane)
3.6 (11.81 ft)	12	(1.58% less than 12 ft. lane)

The Task Force believes that the values established correspond with recent research regarding lane widths and safety benefits (reports TRB 214 and NCHRP 15-12 - the latter currently in progress). Furthermore, construction practices and the pavement striping process generally yield lane widths somewhat less than 9, 10, 11, or 12 ft. The metric values established are typically 1.5 percent below the corresponding English values now specified. This difference is considered negligible with respect to safety benefits. Some capacity reduction may theoretically result, but in practical terms, such a reduction is not expected to be significant.

The 14-foot lane width used on many Interstate ramps will have a 4.2 m metric value.

Surfacing thickness will be identified in 5 mm increments.

Vertical Clearance

Metric Value (m)	English Equivalent (ft.)
3.8	12
4.3	14
4.9	16
5.2	17

The 4.9 m value is seen to be the critical value since the federal legislation required Interstate design to have 16 ft. vertical clearance. The MDT typically utilizes the 4.9 m clearance for arterials and collectors and provides 5.2 m clearances on all Interstate structures for snow storage. An additional 0.15 m may be included in the above clearances for future overlays.

Guardrail Dimensions

The offset from the face of guardrail to the shoulder break behind the guardrail (formerly 3'-3") will now be 1.0 meter.

Barrier Support Spacing

Metric Value (m)	English Equivalent (ft.)
1.905	6.25
3.81	12.5
7.62	25

Barrier support spacings will be soft converted to metric until appropriate criteria are developed.

Clear Zones

The AASHTO Roadside Design Guide will be used for clear zone determinations. Soft conversions will occur until other criteria are developed.

Curbs

Curb Type	Metric Height (mm)	English Equivalent (in.)
Mountable Curb	150 (max)	6
Barrier Curb	225 (max)	9

The definition of high speed/low speed has an impact on where curb is used.

- Low speed: 70 km/h or less design speed
- High speed: over 70 km/h design speed

Sight Distance

Stopping Sight Distance	Metric Value (mm)	English Equivalent (ft.)
Eye Height	1070	3.51
Object Height	150	0.5
Headlight Height	610	2

Passing Sight Distance	Metric Value (mm)	English Equivalent (ft.)
Eye Height	1070	3.51
Object Height	1300	4.27

Sight Distance (Cont.)

Provided are tables III-1, III-2, III-3, and III-4, which were prepared to show various suggested sight distance values.

Design Speed (km/h)	Assumed Speed for Condition (km/h)	Brake Reaction		Coefficient of Friction (f)	Braking Distance on Level (m)	Stopping Sight Distance	
		Time (sec)	Distance (m)			Computed (m)	Rounded for Design (m)
40	40-40	2.5	27.8-27.8	0.38	16.6-16.6	44.4-44.4	50-50
50	47-50	2.5	32.6-34.7	0.35	24.8-28.1	57.4-62.8	60-70
60	55-60	2.5	38.2-41.7	0.33	36.1-42.9	74.3-84.6	80-90
70	63-70	2.5	43.7-48.6	0.31	50.4-62.2	94.1-110.8	100-120
80	70-80	2.5	48.6-55.6	0.30	64.2-83.9	112.8-139.4	120-140
90	77-90	2.5	53.5-62.5	0.30	77.7-106.2	131.2-168.7	140-170
100	85-100	2.5	59.0-69.4	0.29	98.0-135.6	157.0-205.0	160-210
110	91-110	2.5	63.2-76.4	0.28	116.3-170.0	179.5-246.4	180-250

Table III-1. Stopping sight distance (wet pavements). Taken from Chapter 10, MDT Road Design Manual.

Design Speed (km/h)	Maximum e	Maximum f	Total (e+f)	Calculated Radius (meters)	Rounded Radius (meters)
40	0.08	0.17	0.25	50.4	55
50	0.08	0.16	0.24	82.0	85
60	0.08	0.15	0.23	123.2	125
70	0.08	0.14	0.22	175.4	180
80	0.08	0.14	0.22	229.1	230
90	0.08	0.13	0.21	303.7	305
100	0.08	0.11	0.19	393.7	395
110	0.08	0.11	0.19	501.5	505

Table III-2 - Minimum radius determined for limiting values of e and f, rural highways and high speed urban streets. Taken from Chapter 10, MDT Road Design Manual.

Sight Distance (Cont.)

Design Speed (km/h)	Assumed Speed for Condition (km/h)	Coefficient of Friction (f)	Stopping Sight Distance Rounded for Design (m)	Rate of Vertical Curvature, K (length (m) per percent of A)	
				Computed[a]	Rounded for Design
40	40-40	0.38	50-50	6.2-6.2	7-7
50	47-50	0.35	60-70	8.9-12.1	9-13
60	55-60	0.33	80-90	15.8-20.1	16-21
70	63-70	0.31	100-120	24.8-35.6	25-36
80	70-80	0.30	120-140	35.6-48.5	36-49
90	77-90	0.30	140-170	48.5-71.5	49-72
100	85-100	0.29	160-210	63.4-109.2	64-110
110	91-110	0.28	180-250	80.2-154.7	81-155

[a]*Using rounded values of stopping sight distance.*

Table III-3. Design controls for crest vertical curves based on stopping sight distance. Taken from Chapter 10, MDT Road Design Manual.

Design Speed (km/h)	Assumed Speed for Condition (km/h)	Coefficient of Friction (f)	Stopping Sight Distance Rounded for Design (m)	Rate of Vertical Curvature, K (length (m) per percent of A)	
				Computed[a]	Rounded for Design
40	40-40	0.38	50-50	8.4-8.4	9-9
50	47-50	0.35	60-70	10.8-13.4	11-14
60	55-60	0.33	80-90	15.9-18.5	16-19
70	63-70	0.31	100-120	21.2-26.6	22-27
80	70-80	0.30	120-140	26.6-32.0	27-33
90	77-90	0.30	140-170	32.0-40.3	33-41
100	85-100	0.29	160-210	37.5-51.5	38-52
110	91-110	0.28	180-250	43.1-62.7	44-63

[a]*Using rounded values of stopping sight distance.*

Table III-4. Design controls for sag vertical curves based on stopping sight distance. Taken from Chapter 10, MDT Road Design Manual.

Sight Distance (Cont.)

DESIGN SPEED (km/h)	MINIMUM PASSING SIGHT DISTANCE ROUNDED FOR DESIGN (m)	CALCULATED K-VALUES $K = S^2/946$	K-VALUES ROUNDED FOR DESIGN
40	290	88.9	90
50	350	129.5	130
60	430	195.5	195
70	490	253.8	255
80	550	319.8	320
90	615	393.3	395
100	675	474.5	475
110	745	594.6	595

K-values are calculated using the passing sight distance that has been rounded for design
Eye Height = 1070 mm and object height = 1300 mm

K-VALUES FOR PASSING SIGHT DISTANCE

Pipe/Conduit

Steel pipe and copper tube sizes will not change by switching to the metric system. American sizes are used in many parts of the world. Initially, they are simply classified by the nominal mm size, but in the future, hard metric pipe sizes will probably be utilized.

ASTM B88M, which gives standardized hard metric copper tube sizes, will not be utilized until ample product availability can be established. The ASHRAE SI Guide, page 7, chart B.12, "PIPE/CONDUIT", gives the nominal ISO mm size for American pipe, but we have opted to use a hard conversion of 1 in. = 25 mm. Schedule designations remain the same (example: Schedule 40, and type K, L, M).

Nominal Sizes-Tubing and Smooth Wall Pipe	
ISO (mm)	**English (in.)**
3	1/8
6	1/4
10	3/8
13	1/2
16	5/8
19	3/4
25	1
31	1¼
38	1½
50	2
63	2½
75	3
88	3½
100	4
113	4½
125	5
150	6
200	8
250	10

Table of Nominal Pipe Sizes in Inches and Millimeters

Nominal Sizes-RCP	
ISO (mm)	English (in.)
300	12
375	15
450	18
525	21
600	24
675	27
750	30
825	33
900	36
1050	42
1200	48
1350	54
1500	60
1650	66
1800	72
1950	78
2100	84

Table values from "AASHTO Materials, Standard Specifications for Transportation Materials, Part 1, "M170M.

Note: RCP will be identified by the metric sizes shown above. Until the industry converts to metric, there will be no physical product change. Current accepted tolerances allow English sizes to meet metric size requirements.

REINFORCED CONCRETE PIPE ARCHES

ISO		
SPAN (mm)	RISE (mm)	EQUIVALENT DIAMETER (mm)
460	280	375
560	345	450
660	395	525
725	460	600
920	570	750
1110	675	900
1300	795	1050
1485	915	1200
1650	1015	1350
1855	1145	1500
2235	1370	1800
2590	1575	2100
2920	1830	2250
3100	1960	2400

ENGLISH		
SPAN (in.)	RISE (in.)	EQUIVALENT DIAMETER (in.)
18	11	15
22	14	18
26	16	21
29	18	24
36	22	30
44	27	36
51	31	42
59	36	48
65	40	54
73	45	60
88	54	72
102	62	84
115	72	90
122	77	96

Table values from "AASHTO Materials, Standard Specifications for Transportation Materials, Part 1, M206M.

Note: 1. **RCP arches will be identified by the metric sizes shown above. Until the industry converts to metric, there will be no physical product change. Current accepted tolerances allow English sizes to meet metric size requirements.**

2. **English span and rise dimensions are rounded to the nearest inch.**

CORRUGATED STEEL PIPE

68 mm x 13mm Corrugations
(2⅔ in. x ½ in. Corrugations)

PIPE DIAMETER	
ISO (mm)	ENGLISH (in.)
300	12
400	15
450	18
500	21
600	24
700	-
800	30
900	36
1000	42
1200	48
1400	54
-	60
1600	-
-	66
1800	72
2000	78

Table values from "AASHTO Materials, Standard Specifications for Transportation Materials, Part 1," M36M.

Note: CSP will be hard converted to metric sizes. In other words, there will be a physical product change and the metric sizes will approximate the previous English sizes as shown above.

CORRUGATED STEEL PIPE (CONT.)

75 mm x 25 mm or 125 mm x 25 mm Corrugations
(3 in. x 1 in. or 5 in. x 1 in. Corrugations)

PIPE DIAMETER	
ISO (mm)	ENGLISH (in.)
1400	54
-	60
1600	-
-	66
1800	72
2000	78
2200	84
-	90
2400	96
-	102
2700	108
-	114
3000	120

Table values from "AASHTO Materials, Standard Specifications for Transportation Materials, Part 1," M36M.

Note: CSP will be hard converted to metric sizes. In other words, there will be a physical product change and the metric sizes will approximate the previous English sizes as shown above.

CORRUGATED STEEL PIPE ARCHES

68 mm x 13 mm corrugations

ISO		
SPAN (mm)	RISE (mm)	EQUIVALENT DIAMETER (mm)
450	340	400
510	380	450
560	420	500
680	500	600
800	580	700
910	660	800
1030	740	900
1150	820	1000
1390	970	1200
1680	1120	1400
1880	1260	1600
2130	1400	1800

2⅔ in. x ½ in. corrugations

English		
SPAN (in)	RISE (in)	EQUIVALENT DIAMETER (in)
17	13	15
21	15	18
24	18	21
28	20	24
35	24	30
42	29	36
49	33	42
57	38	48
64	43	54
71	47	60
77	52	66
83	57	72

Table values from "AASHTO Materials, Standard Specifications for Transportation Materials, Part 1, M36M.

Note: English to metric conversion cannot be read directly across in these tables, consult the Hydraulics Section for equivalent arch sizes.

CORRUGATED STEEL PIPE ARCHES (Cont.)

75 mm x 25 mm Corrugations
or
125 mm x 25 mm Corrugations

ISO		
SPAN (mm)	RISE (mm)	EQUIVALENT DIAMETER (mm)
1330	1030	1200
1550	1200	1400
1780	1360	1600
2080	1530	1800
2230	1700	2000
2500	1830	2200
2800	1950	2400
3300	2080	2700

3 in. x 1 in Corrugations
or
5 in. x 1 in. Corrugations

English		
SPAN (in)	RISE (in)	EQUIVALENT DIAMETER (in)
53	41	48
60	46	54
66	51	60
73	55	66
81	59	72
87	63	78
95	67	84
103	71	90
112	75	96
117	79	102
128	83	108

Table values from AASHTO Materials, Standard Specifications for Transportation Materials, Part 1," M36M.

Note:

1. **CSP arches will be hard converted to metric sizes. In other words, there will be a physical product change and the metric sizes will approximate the previous English sizes as shown above.**

2. **English to metric conversion cannot be read directly across in these tables, consult the Hydraulics Section for equivalent arch sizes.**

CORRUGATED LOCKSEAM ALUMINUM PIPE

68 mm x 13 mm Corrugations
(2⅔ in. x ½ in. Corrugations)

PIPE DIAMETER	
ISO (mm)	ENGLISH (in.)
300	12
400	15
450	18
600	24
800	30
900	36
1000	42
1200	48
1400	54
1600	-
1800	72

75 mm x 25 mm Corrugations
(3 in. x 1 in. Corrugations)

PIPE DIAMETER	
ISO (mm)	ENGLISH (in.)
800	30
900	36
1000	42
1200	48
1400	54
1600	-
1800	72

NOTE: Corrugated aluminum pipe will be hard converted to metric sizes. In other words, there will be a physical product change and the metric sizes will approximate the previous English sizes as shown above.

STRUCTURAL STEEL PLATE PIPE

150 mm x 50 mm Corrugations
(6 in. x 2 in. Corrugations)

PIPE DIAMETER	
ISO (m)	ENGLISH (in.)
1.524	60
1.829	72
2.134	84
2.438	96
2.743	108
3.048	120
3.353	132
3.658	144
3.962	156
4.267	168
4.572	180
4.877	192
5.182	204
5.486	216
5.791	228
6.096	240
6.401	252

NOTE: Structural steel plate pipe will be soft converted to metric sizes. In other words, there will be no physical product change and the metric sizes will be identified in meters to 0.001 m.

STRUCTURAL STEEL PLATE PIPE ARCHES

150 mm x 50 mm Corrugations with 457 mm corner radius
(6 in. x 2 in. Corrugations with 18 in. corner radius)

PIPE DIMENSIONS SPAN AND RISE	
ISO (m)	ENGLISH (ft. - in.)
1.854 x 1.397	6-1 x 4-7
1.930 x 1.448	6-4 x 4-9
2.134 x 1.549	7-0 x 5-1
2.210 x 1.600	7-3 x 5-3
2.337 x 1.651	7-8 x 5-5
2.489 x 1.753	8-2 x 5-9
2.692 x 1.854	8-10 x 6-1
2.972 x 2.007	9-9 x 6-7
3.251 x 2.108	10-8 x 6-11
3.327 x 2.159	10-11 x 7-1
3.607 x 2.311	11-10 x 7-7
3.861 x 2.464	12-8 x 8-1
3.912 x 2.540	12-10 x 8-4
4.089 x 2.565	13-5 x 8-5

150 mm x 50 mm Corrugations with 787 mm corner radius
(6 in. x 2 in. Corrugations with 31 in. corner radius)

PIPE DIMENSIONS SPAN AND RISE	
ISO (m)	ENGLISH (ft. - in.)
4.115 x 2.896	13-6 x 9-6
4.318 x 2.997	14-2 x 9-10
4.750 x 3.200	15-7 x 10-6
4.826 x 3.251	15-10 x 10-8
5.232 x 3.454	17-2 x 11-4
5.461 x 3.556	17-11 x 11-8
5.512 x 3.607	18-1 x 11-10
5.715 x 3.708	18-9 x 12-2
6.071 x 3.912	19-11 x 12-10
6.274 x 4.013	20-7 x 13-2

Note: **Structural steel plate pipe arches will be soft converted to metric sizes. In other words, there will be no physical product change and the metric sizes will be identified in meters to 0.001 m.**

Pipe/Conduit (Cont.)

Pipe Thickness/Zinc Coated CSP	
AASHTO SI (mm)	English Value (in.)
1.02	0.040
1.32	0.052
1.63	0.064
2.01	0.079
2.77	0.109
3.51	0.138
4.27	0.168

Pipe Corrugation Size		
AASHTO SI (mm)		English Equivalent (in.)
68 x 13	(2.68 in. x .512 in.)	2⅔ x ½
75 x 25	(2.95 in. x .984 in.)	3 x 1
125 x 25	(4.921 in. x .984 in.)	5 x 1
150 x 150	(5.905 in. x 1.968 in.)	6 x 2

Culvert Length

Metric culverts will be specified in multiples of 0.5 m lengths. Specify the next highest length of culvert required in 0.5 m increments.

Existing English culverts shall be measured to the nearest 0.1 m length.

NOTE: PRODUCT AVAILABILITY SHOULD BE CHECKED WITH THE SUPPLIER PRIOR TO THE PRODUCT BEING SPECIFIED.

COST ESTIMATION

Cost estimating will require converting historical cost data (average bid prices, etc.) to the appropriate metric units.

There is no major impact to the bid letting and award process for MDT. The contractors will be forced to submit bids with item quantities in metric units; but otherwise, there will be no changes in this area.

The brunt of the impact of this conversion will be felt by the Contract Plans Section.

CRANE BINDER
800 298 5555

CHAPTER FOUR

Structures

The following standards shall be used in the conversion of Bridge Bureau activities to the metric system.

- Long Bridges will be those over 60 m in length.

- The bridge design detail and rating manuals shall be converted to metric. All plans and specifications prepared within the Bureau and to be included in PS&E packages advertised after September 30, 1996, will be in metric units.

- All inspection reports shall be reported in metric units beginning January 1, 1995. No conversion is necessary for reports prior to that date.

- Formula conversions contained with the current AASHTO Standard Specifications for Highway Bridges and Structures, Fifteenth Edition, Appendix E, Metric Equivalents of U.S. Customary Units shall be used in computations. These conversions represent a soft conversion of all formulas within the specifications. Information Systems will be requested to prepare our computer programs for metric computations. Computer programs not within the control of MDT will hopefully be converted by the manager of the programs. Such programs include, PONTIS, SEISAB, LPILE, etc.

- Conversions of all prefabricated elements shall be made on a soft conversion basis unless and until industry modifies the dimensions of current products, such as prestressed girders, structural members, etc.

- All equipment purchased after January 1, 1995, shall be capable of displaying metric units. This does not preclude purchasing equipment capable of displaying metric units prior to that date as new or replacement equipment.

- Structural calculations should be done in metric, but for computer programs and/or other information not available in metric, soft conversion is acceptable to complete projects.

- Since no international trend exists on standardization of steel shapes, metric projects shall use the same steel shapes currently used, only use the metric dimensions listed in ASTM A6/A6M. A6/A6M lists both inch and mm dimensions of the shapes. All LRFD property, shape, and specification design data is available in metric from AISC for A6/A6M steel shapes (Phone Orders: AISC, Chicago, IL, (312)670-5414).

DRAWING SCALES

AIA preferred metric scales, all multiples of 1, 2, or 5 shall be used in preparation of metric scaled engineering drawings:

Metric Scales	Architectural
1:2	1:2
1:5	3" = 1'
1:10	1½" = 1' 1" = 1'
1:20	¾" = 1' ½" = 1'
1:50	¼" = 1'
1:100	⅛" = 1'
1:200	1/16" = 1' 1" = 20'
1:500	1/32" = 1' 1" = 40' 1" = 50'
1:1000	1" = 80' 1" = 100'

FASTENERS

- Large projects shall use ASTM A325 and A490M metric bolts.
- There are four standard metric bolt sizes, which replace the nine bolts currently used. They are sizes 16, 20, 22, and 24 mm. The 24 mm bolts can be used with the Bridge Engineer's approval.
- Minimum order quantities may apply, so small metric projects should verify availability during design.

UNITS USED ON DRAWINGS

- SI drawings shall use millimeters exclusively, except that elevations and layout dimensions will be called out in meters on the General Layout and Footing Plan Sheets.

- So that it is not necessary to write "mm" after each dimension, each drawing should have the following note on it: "ALL DIMENSIONS ARE MILLIMETERS (mm) UNLESS OTHERWISE NOTED".

- SI drawings should almost never show decimal millimeters (e.g. 2034.5), unless a high precision part or product thickness is being detailed. Use whole millimeters (2035).

- Dual dimensions shall not be used on SI drawings.

- Shop drawings shall be submitted using millimeters only.

Other metric units to be used within the Bureau include:

- The kilogram (kg) is the base unit for mass.

- The newton (N) is the derived unit of force (mass x acceleration = (kgm/s^2)).

- The Pascal (Pa) is the unit of pressure and stress (Pa = N/m^2).

- Structural calculations preferably shall be shown in MPa or kPa.

- Loads preferably shall be specified in kilopascals (kPa).

- Plane angles will continue to be designated in degrees (degrees, minutes, and seconds).

- Slope is expressed in non-dimensional ratios. The horizontal component is shown first and then the vertical. For instance, a rise of one meter in four meters is expressed as 4:1. The units that are compared should be the same (meters to meters, millimeters to millimeters, etc.).

- The table in Chapter One (Civil and Structural Engineering Conversion Factors) contains the engineering conversion factors which shall be used by all personnel of the Bureau.

UNITS USED ON DRAWINGS (Cont'd)

Miscellaneous	
Metric Value	**U.S. Equivalent**
96.6 km/h	60 mph
160.9 km/h	100 mph
9.81 m/s^2	32.2 ft/s^2
232.77 mm^2/m	0.11 $in^2/ft.$
265 mm^2/m	⅛ $in^2/ft.$
529 mm^2/m	0.25 $in^2/ft.$
0.052 m/m	⅝ in/ft.
0.035 m/1000 kg	1¼ in/Ton
M13.5	H 15
M18	H 20
MS	HS
MS13	HS 15
MS18	HS 20
Tons (1000 kg)	Tons (2000 lbs.)

UNITS USED ON DRAWINGS (Cont'd)

The following chart gives the new kPa loads that shall be used to replace the psf loads.

Metric Value (kPa)	English Equivalent (psf)	Percent Metric is Stronger
2.5	50	4.4
3.9	80	1.8
4.5	85	10.6
5	100	4.4
6	120	4.4
7.5	150	4.4
10	200	4.4
12	250	0.2
15	300	4.4
17	350	1.4
20	400	4.4
22	450	2.1
24	500	0.2
31	640	1.2

UNITS FOR STRUCTURAL STEEL DESIGN

Although there are seven metric base units in the SI system, only four are currently used by AISC in structural steel design. These base units are listed in the following table.

Quantity	Unit	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
temperature	Celsius	°C

Similarly, of the numerous decimal prefixes included in the SI system, only three are used in steel design.

Prefix	Symbol	Order of Magnitude	Expression
mega	M	10^6	1 000 000 (one million)
kilo	k	10^3	1000 (one thousand)
milli	m	10^{-3}	0.001 (one thousandth)

In addition, three derived units are applicable to the present conversion.

Quantity	Name	Symbol	Expression
force	newton	N	$N = kgm/s^2$
stress	pascal	Pa	$Pa = N/m^2$
energy	joule	J	$J = Nm$

Although specified in SI, the pascal is not universally accepted as the unit of stress. Because section properties are expressed in millimeters, it is more convenient to express stress in newtons per square millimeter ($1\ N/mm^2 = 1\ MPa$). It should be noted that the joule, as the unit of energy, is used to express energy absorption requirements for impact tests. Moments are expressed in terms of Nm.

The following conversion factors relate traditional U.S. units of measurement to the corresponding SI units:

Multiply	by:	to obtain:
inch (in.)	25.4	millimeters (mm)
foot (ft.)	304.8	millimeters (mm)
pound-mass (lb)	0.454	kilogram (kg)
pound-force (lbf)	4.448	newton (N)
ksi	6.895	N/mm^2
ft-lbf	1.356	joule (J)

Note that fractions resulting from metric conversion should be rounded to whole millimeters. Following are common fractions of inches and their metric equivalent.

Fraction (in.)	Exact Conversion (mm)	Rounded to: (mm)
1/16	1.587 5	2
1/8	3.175	3
3/16	4.762 5	5
1/4	6.35	6
5/16	7.937 5	8
3/8	9.525	10
7/16	11.112 5	11
1/2	12.7	13
5/8	15.875	16
3/4	19.05	19
7/8	22.225	22
1	25.4	25

Bolt diameters are taken directly from the ASTM Specification A325 and A490M. The metric bolt designations are as follows:

Designation	Diameter (mm)	Diameter (in.)
M16	16	0.63
M20	20	0.79
M22	22	0.87
M24	24	0.94
M27*	27	1.06
M30*	30	1.18
M36*	36	1.42

*Not currently used by MDT Bridge Bureau

The yield strengths of structural steels covered in the metric LRFD Specification are taken from the metric ASTM Specifications. It should be noted that the yield points are slightly different from the traditional values.

ASTM Designation	Yield stress (MPa)	Yield stress (ksi)
A36M	250	36.26
A572M Gr. 345 A588M	345	50.04
A852M	485	70.34
A514M	690	100.07

On the basis of the above selection of units and conversion factors, the 1986 LRFD[1] Specification has been translated into the SI system. When necessary, formulas were revised to make all coefficients non-dimensional. In most instances, this could be achieved by explicitly showing the modulus of elasticity, E, in the formulation.

The converted LRFD Specification is offered to the federal agencies and consultants as an interim document to facilitate design of metric demonstration projects. It will also serve as an introduction of the SI units of measurement to the general design profession and fabricating industry. More complete information is available in the Metric Guide for Federal Construction, First Edition, prepared by the Construction Subcommittee of the Metrication Operating Committee. The guide is available from the National Institute of Building Sciences in Washington, D.C. (Call 202-289-7800 for ordering information).

[1]American Institute of Steel Construction, Load and Resistance Factor Design, 1986.

For convenience and completeness, a copy of the AASHTO expressions is reproduced within this manual. The metric expressions come from Appendix E, of the Standard Specifications for Highway Bridges, 15th Edition, AASHTO, 1992 (with Interim 1993).

Note: A list of the nomenclature and units for the AASHTO equations shown here and on the next pages, is available following the AASHTO equations in this manual.

AASHTO EXPRESSIONS

U.S. Customary	Equation	Metric
Article 2.7.4.3		
$\frac{1600}{\sqrt{F_y}}$	2-1	$\frac{133}{\sqrt{F_y}}$
$\frac{6000}{\sqrt{F_y}}$	2-2	$\frac{499}{\sqrt{F_y}}$
$\frac{13\,300}{\sqrt{F_y}}$	2-3	$\frac{1106}{\sqrt{F_y}}$
$\frac{13\,300\left[1 - 1.43\left(\frac{f_a}{F_a}\right)\right]}{\sqrt{F_y}}$	2-4	$\frac{1106\left[1 - 1.43\left(\frac{f_a}{F_a}\right)\right]}{\sqrt{F_y}}$
$\frac{7000}{\sqrt{F_y}}$	2-5	$\frac{581}{\sqrt{F_y}}$
$\frac{2400\ b}{\sqrt{F_y}}$	2-6	$\frac{199.2\ b}{\sqrt{F_y}}$
$\frac{20\,000\,000\ A_f}{dF_y}$	2-7	$\frac{137\,640\ A_f}{dF_y}$
Figure 2.7.4B		
$1 + \frac{h - 33}{18}$		$1 + \frac{h}{0.457} - \frac{33}{18}$
Article 3.8.2		
$\frac{50}{L + 125}$	3-1	$\frac{15.24}{L + 38}$
Article 3.10		
$\frac{6.68S^2}{R}$	3-2	$\frac{0.79S^2}{R}$
Article 3.14.1		
$\left(30 + \frac{3000}{L}\right)\left(\frac{55 - W}{50}\right)$	3-3	$\left(1435 + \frac{43\,800}{L}\right)\left(\frac{16.7 - W}{15.2}\right)$
Article 3.24.3		
$\left(\frac{S + 2}{32}\right) P_{20}$	3-15	$\left(\frac{S + 0.61}{9.74}\right) P_{18}$
$\left(\frac{S + 2}{32}\right) P_{15}$	3-16	$\left(\frac{S + 0.61}{9.74}\right) P_{13.5}$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 3.24.5.1		
$0.8X + 3.75$	3-17	$0.8X + 1.143$
$0.35X + 3.2$	3-18	$0.35X + 0.98$
Article 3.24.10.2		
$\frac{100}{\sqrt{S}}$	3-21	$\frac{55}{\sqrt{S}}$
$\frac{220}{\sqrt{S}}$	3-22	$\frac{121}{\sqrt{S}}$
Article 3.25.1		
$P[0.51 \log_{10} s - k]$	3-23	$P[0.51 \log_{10} (39.36s) - k]$
$\frac{1000}{\sigma_{PL}} \times \left[\frac{\overline{R_y}}{R_D} + \frac{\overline{M_y}}{M_D} \right]$	3-27	$\frac{6.895}{\sigma_{PL}} \times \left[\frac{\overline{R_y}}{R_D} + \frac{\overline{M_y}}{M_D} \right]$
$\left(\frac{P}{2s}\right)(s - 20)$	3-29	$\left(\frac{P}{2s}\right)(s - 0.50)$
$\left(\frac{Ps}{1600}\right)(s - 10)$	3-30	$\left(\frac{Ps}{40}\right)(s - 0.25)$
$\left[\frac{Ps}{20}\right]\left[\frac{(s - 30)}{(s - 10)}\right]$	3-31	$\left[\frac{Ps}{20}\right]\left[\frac{(s - 0.75)}{(s - 0.25)}\right]$
Article 4.4.12.2		
$5\sqrt{f'_c}$		$0.415\sqrt{f'_c}$
Article 8.5.3		
$0.000\,006$ *per* °F		$0.000\,010\,8$ *per* °C
Article 8.7.1		
$w_c^{1.5}\sqrt{f'_c}$		$w_c^{1.5}(0.042\,8)\sqrt{f'_c}$
$57\,000\sqrt{f'_c}$		$4729.77\sqrt{f'_c}$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 8.15.2.1.1		
$7.5\sqrt{f'_c}$		$0.623\sqrt{f'_c}$
$6.3\sqrt{f'_c}$		$0.523\sqrt{f'_c}$
$5.5\sqrt{f'_c}$		$0.456\sqrt{f'_c}$
Article 8.15.5.2.1		
$0.95\sqrt{f'_c}$		$0.079\sqrt{f'_c}$
$0.9\sqrt{f'_c} + 1100\rho_w\left(\frac{Vd}{M}\right) \le 1.6\sqrt{f'_c}$	8-4	$0.075\sqrt{f'_c} + 7.58\rho_w\left(\frac{Vd}{M}\right) \le 0.133\sqrt{f'_c}$
Article 8.15.5.2.2		
$0.9\left(1 + 0.000\,6\,\frac{N}{A_g}\right)\sqrt{f'_c}$	8-5	$10.84\left(0.006\,8 + 0.000\,6\,\frac{N}{A_g}\right)\sqrt{f'_c}$
Article 8.15.5.2.3		
$0.9\left(1 + 0.004\,\frac{N}{A_g}\right)\sqrt{f'_c}$	8-6	$10.84\left(0.006\,8 + 0.004\,\frac{N}{A_g}\right)\sqrt{f'_c}$
Article 8.15.5.3.4		
$1.5\sqrt{f'_c}$		$0.125\sqrt{f'_c}$
Article 8.15.5.3.8		
$2\sqrt{f'_c}$		$0.166\sqrt{f'_c}$
Article 8.15.5.3.9		
$4\sqrt{f'_c}$		$0.332\sqrt{f'_c}$
Article 8.15.5.6.3		
$\left(0.8+\frac{2}{\beta_c}\right)\sqrt{f'_c} \le 1.8\sqrt{f'_c}$	8-13	$\left(0.066+\frac{0.166}{\beta_c}\right)\sqrt{f'_c} \le 0.149\sqrt{f'_c}$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 8.15.5.6.4		
$0.9\sqrt{f'_c}$		$0.075\sqrt{f'_c}$
$3\sqrt{f'_c}$		$0.249\sqrt{f'_c}$
Article 8.15.5.7		
$\sqrt{f'_c} + 2200\rho\frac{Vd}{M}$	8-14	$0.083\sqrt{f'_c} + 15.168\rho\frac{Vd}{M}$
$1.8\sqrt{f'_c}$		$0.149\sqrt{f'_c}$
$1.4\sqrt{f'_c}$		$0.116\sqrt{f'_c}$
$1.2\sqrt{f'_c}$		$0.100\sqrt{f'_c}$
Article 8.16.3.2.2		
$\frac{0.85\beta_1 f'_c}{f_y}\left(\frac{87\ 000}{87\ 000 + f_y}\right)$	8-18	$\frac{0.85\beta_1 f'_c}{f_y}\left(\frac{599.843}{599.843 + f_y}\right)$
Article 8.16.3.3.3		
$\left(\frac{b_w}{b}\right)\left[\left(\frac{0.85\beta_1 f'_c}{f_y}\right)\left(\frac{87\ 000}{87\ 000 + f_y}\right) + \rho_f\right]$	8-22	$\left(\frac{b_w}{b}\right) \times \left[\left(\frac{0.85\beta_1 f'_c}{f_y}\right)\left(\frac{599.843}{599.843 + f_y}\right) + \rho_f\right]$
Article 8.16.3.4.1		
$0.85\beta_1\left(\frac{f'_c d'}{f_y d}\right)\left(\frac{87\ 000}{87\ 000 - f_y}\right)$	8-24	$0.85\beta_1\left(\frac{f'_c d'}{f_y d}\right)\left(\frac{599.843}{599.843 - f_y}\right)$
Article 8.16.3.4.3		
$\left[\left(\frac{0.85\beta_1 f'_c}{f_y}\right)\left(\frac{87\ 000}{87\ 000 + f_y}\right)\right] + \rho'\left(\frac{f'_s}{f_y}\right)$	8-27	$\left[0.85\beta_1\left(\frac{f'_c}{f_y}\right)\left(\frac{599.843}{599.843 + f_y}\right)\right] + \rho\left(\frac{f'_s}{f_y}\right)$
$87\ 000\left[1 - \left(\frac{d'}{d}\right)\left(\frac{87\ 000 + f_y}{87\ 000}\right)\right]$	8-28	$599.843\left[1 - \left(\frac{d'}{d}\right)\left(\frac{599.843 + f_y}{599.843}\right)\right]$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 8.16.6.2.1		
$1.9\sqrt{f'_c} + 2500\rho_w\left(\frac{V_u d}{M_u}\right)$	8-48	$0.158\sqrt{f'_c} + 17.2\rho_w\left(\frac{V_u d}{M_u}\right)$
$2\sqrt{f'_c}$	8-49	$0.166\sqrt{f'_c}$
$3.5\sqrt{f'_c}$		$0.291\sqrt{f'_c}$
Article 8.16.6.2.2		
$2\left(1 + \frac{N_u}{2000\ A_g}\right)\sqrt{f'_c}$	8-50	$24.1\left(0.006\ 8 + \frac{N_u}{2000\ A_g}\right)\sqrt{f'_c}$
$2\sqrt{f'_c}$	8-51	$0.166\sqrt{f'_c}$
Article 8.16.6.2.3		
$2\left(1 + \frac{N_u}{500\ A_g}\right)\sqrt{f'_c}$	8-52	$24.1\left(0.006\ 8 + \frac{N_u}{500\ A_g}\right)\sqrt{f'_c}$
Article 8.16.6.3.4		
$3\sqrt{f'_c}$	8-55	$0.249\sqrt{f'_c}$
Article 8.16.6.3.8		
$4\sqrt{f'_c}$		$0.332\sqrt{f'_c}$
Article 8.16.6.3.9		
$8\sqrt{f'_c}$		$0.664\sqrt{f'_c}$
Article 8.16.6.6.2		
$\left(2 + \frac{4}{\beta_c}\right)\sqrt{f'_c} \le 4\sqrt{f'_c}$	8-58	$0.083\left(2 + \frac{4}{\beta_c}\right)\sqrt{f'_c} \le 0.332\sqrt{f'_c}$
Article 8.16.6.6.3		
$6\sqrt{f'_c}$		$0.498\sqrt{f'_c}$
$2\sqrt{f'_c}$		$0.166\sqrt{f'_c}$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 8.16.6.7.1		
$2.14\sqrt{f'_c} + 4600\rho\frac{V_u d}{M_u}$	8-59	$0.178\sqrt{f'_c} + 31.716\rho\frac{V_u d}{M_u}$
$4\sqrt{f'_c}$		$0.332\sqrt{f'_c}$
$3\sqrt{f'_c}$		$0.249\sqrt{f'_c}$
$2.5\sqrt{f'_c}$		$0.208\sqrt{f'_c}$
Article 8.16.8.3		
$21 - 0.33 f_{min} + 8(r/h)$	8-60	$144.790 - 0.33 f_{min} + 55.12(r/h)$
Article 8.19.1.2		
$\frac{50\ b_w\ s}{f_y}$	8-64	$\frac{0.344\ 750\ b_w\ s}{f_y}$
Article 8.25.1		
$\frac{0.04\ A_b\ f_y}{\sqrt{f'_c}}$		$\frac{18.97\ A_b\ f_y}{\sqrt{f'_c}}$
$0.000\ 4\ d_b\ f_y$		$5.8 \times 10^{-2}\ d_b\ f_y$
$\frac{0.085\ f_y}{\sqrt{f'_c}}$		$\frac{0.026\ f_y}{\sqrt{f'_c}}$
$\frac{0.11\ f_y}{\sqrt{f'_c}}$		$\frac{0.034\ f_y}{\sqrt{f'_c}}$
$\frac{0.03\ d_b\ f_y}{\sqrt{f'_c}}$		$\frac{0.361\ d_b\ f_y}{\sqrt{f'_c}}$
Article 8.25.2		
$\frac{6.7\sqrt{f'_c}}{f_{ct}}$		$\frac{0.556\sqrt{f'_c}}{f_{ct}}$
Article 8.26.1		
$\frac{0.02\ d_b\ f_y}{\sqrt{f'_c}}$		$\frac{0.240\ d_b\ f_y}{\sqrt{f'_c}}$
$0.000\ 3\ d_b\ f_y$		$0.043\ d_b\ f_y$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 8.30.1.2		
$\frac{0.03\ d_b\ (f_y - 20\ 000)}{\sqrt{f'_c}}$	8-66	$\frac{0.36\ d_b\ (f_y - 137.895)}{\sqrt{f'_c}}$
$0.20\ \frac{A_w}{S_w} \cdot \frac{f_y}{\sqrt{f'_c}}$	8-67	$2.4\ \frac{A_w}{S_w} \cdot \frac{f_y}{\sqrt{f'_c}}$
Article 8.30.2.1		
$0.27\ \frac{A_w}{S_w} \cdot \frac{f_y}{\sqrt{f'_c}}$	8-68	$3.24\ \frac{A_w}{S_w} \cdot \frac{f_y}{\sqrt{f'_c}}$
Article 9.15.2.1		
$3\sqrt{f'_{ci}}$		$0.249\sqrt{f'_{ci}}$
$7.5\sqrt{f'_{ci}}$		$0.623\sqrt{f'_{ci}}$
Article 9.15.2.2		
$6\sqrt{f'_c}$		$0.498\sqrt{f'_c}$
$3\sqrt{f'_c}$		$0.249\sqrt{f'_c}$
Article 9.15.2.3		
$7.5\sqrt{f'_c}$		$0.623\sqrt{f'_c}$
$6.3\sqrt{f'_c}$		$0.523\sqrt{f'_c}$
$5.5\sqrt{f'_c}$		$0.457\sqrt{f'_c}$
Article 9.16.2.1.1		
$17\ 000-150\ RH$		$117.21-1.034\ RH$
$0.80\,(17\ 000-150\ RH)$		$0.80\,(117.21-1.034\ RH)$
Article 9.16.2.1.2		
$E = 33\,w_c^{1.5}\sqrt{f'_{ci}}$		$E = 0.042\ 8\,w_c^{1.5}\sqrt{f'_{ci}}$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 9.16.2.1.4		
$20\,000-0.4ES-0.2(SH+CR_c)$	9-10	$137.9-0.4ES-0.2(SH+CR_c)$
$20\,000-0.3FR-0.4ES-0.2(SH+CR_c)$	9-11	$137.9-0.3FR-0.4ES-0.2(SH+CR_c)$
$18\,000-0.3FR-0.4ES-0.2(SH+CR_c)$	9-12	$124.10-0.3FR-0.4ES-0.2(SH+CR_c)$
Article 9.17.4.1		
$f_{se}+15\,000$	9-18	$f_{se}+103.421$
Article 9.17.4.2		
$\frac{l_x}{D}+\frac{2}{3}\ f_{se}$	9-19	$6.895\frac{l_x}{D}+\frac{2}{3}\ f_{se}$
Article 9.20.2.2		
$0.6\sqrt{f'_c}b'd+V_d+\frac{V_iM_{cr}}{M_{max}}$	9-27	$4.98\times10^{-4}\sqrt{f'_c}\ b'd+V_d+\frac{V_iM_{cr}}{M_{max}}$
$1.7\sqrt{f'_c}\ b'd$		$0.141\ 2\sqrt{f'_c}\ b'd$
$\frac{1}{Y_t}(6\sqrt{f'_c}+f_{pe}-f_d)$	9-28	$\frac{1}{Y_t}(0.498\sqrt{f'_c}+f_{pe}-f_d)$
Article 9.20.2.3		
$(3.5\sqrt{f'_c}+0.3\,f_{pe})\,b'd+V_p$	9-29	$10\times10^5(0.29\sqrt{f'_c}+0.3\,f_{pe})\,b'd+V_p$
Article 9.20.3.1		
$8\sqrt{f'_c}\ b'd$		$0.664\sqrt{f'_c}\ b'd$
Article 9.20.3.2		
$4\sqrt{f'_c}\ b'd$		$0.332\sqrt{f'_c}\ b'd$
Article 9.20.3.3		
$\frac{50\ b's}{f_{sy}}$	9-31	$\frac{0.345\ b's}{f_{sy}}$
Article 9.27.1		
$\left(f^*_{su}-\frac{2}{3}\,f_{se}\right)D$	9-32	$\frac{1}{6.895}\left(f^*_{su}-\frac{2}{3}\,f_{se}\right)D$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
LArticle 10.2.2		
0.000 006 5 *per* °*F*		11×10^{-6} *per* °*C*
Article 10.15.2.1		
$\frac{14bD}{\sqrt{F_y}\psi t_w}$		$\frac{1.162bD}{\sqrt{F_y}\psi t_w}$
$\frac{7500b}{F_y\psi}$		$\frac{51.69b}{F_y\psi}$
Article 10.15.3		
$\Delta_R=\frac{0.02L^2F_y}{EY_o}\left(\frac{1000-R}{850}\right)$		Metric Equivalent Not Given by AASHTO
Article 10.16.11		
$\frac{11\ 000}{\sqrt{F_y}}$		$\frac{913}{\sqrt{F_y}}$
Article 10.20.2.1		
$(0.227\ 2L-11)\ S_d^{-2/3}$	10-6	$(0.339L-4.98)\ S_d^{-2/3}$
$(0.059L-0.64)\ S_d^{-1/2}$	10-7	$(0.106\ 8L-0.353)\ S_d^{-1/2}$
$\frac{72M_{cb}}{t_fb_f^2}$		$\frac{6M_{cb}}{t_fb_f^2}$
$M_{cb}=0.08WS_d^2$		Metric Equivalent Not Given by AASHTO
Article 10.20.2.2		
$F_D=1.14WS_d$	10-10	Metric Equivalent Not Given by AASHTO
Article 10.25.3		
$\left[\frac{3}{4}+\frac{(yield\ point\ of\ steel)}{400\ 000}\right]$	10-11	$\left[\frac{3}{4}+\frac{(yield\ point\ of\ steel)}{2758}\right]$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Table 10.32.1A		
$F_b=\frac{50\times10^6}{S_{xc}}C_b\left(\frac{I_{yc}}{l}\right)\sqrt{\frac{0.772J}{I_{yc}}+9.87\left(\frac{d}{l}\right)^2}$		Metric Equivalent Not Given by AASHTO
$16\ 980-0.53(KL/r)^2$		Metric Equivalent Not Given by AASHTO
$23\ 580-1.03(KL/r)^2$		Metric Equivalent Not Given by AASHTO
$33\ 020-2.02(KL/r)^2$		Metric Equivalent Not Given by AASHTO
$47\ 170-4.12(KL/r)^2$		Metric Equivalent Not Given by AASHTO
$\frac{135\ 000\ 740}{(KL/r)^2}$		Metric Equivalent Not Given by AASHTO
$42\ 450-3.33(KL/r)^2$		$292.682-0.023(KL/r)^2$
Article 10.32.3.3.3		
$F_s\ (1-1.59\times10^{-2}f_t)$		$F_s\left(1-1.59\times10^{-2}\frac{f_t}{0.006\ 89}\right)$
$F_s\ (1-1.27\times10^{-2}f_t)$		$F_s\left(1-1.27\times10^{-2}\frac{f_t}{0.006\ 89}\right)$
Article 10.32.4.2		
$\left(\frac{F_y-13\ 000}{20\ 000}\right)600d$	10-17	$\left(\frac{F_y-89.50}{137.90}\right)4.137d$
$\left(\frac{F_y-13\ 000}{20\ 000}\right)3000\sqrt{d}$	10-18	$\left(\frac{F_y-89.50}{137.90}\right)3.32\sqrt{d}$
Article 10.34.2.1.3		
$\frac{3250}{\sqrt{f_b}}$	10-19	$\frac{270}{\sqrt{f_b}}$
Article 10.34.2.1.5		
$\frac{3860}{\sqrt{f_{d11}}}$	10-20	$\frac{320.38}{\sqrt{f_{d11}}}$
Article 10.34.2.2.2		
$\frac{1625}{\sqrt{f_b}}$	10-21	$\frac{134.875}{\sqrt{f_b}}$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 10.34.2.2.4		
$\frac{1930}{\sqrt{f_{d11}}}$	10-22	$\frac{160.39}{\sqrt{f_{d11}}}$
Article 10.34.3.1.1		
$\frac{D\sqrt{f_b}}{23\ 000}$	10-23	$\frac{D\sqrt{f_b}}{1909}$
Article 10.34.3.2.1		
$\frac{D\sqrt{f_b}}{46\ 000}$	10-24	$\frac{D\sqrt{f_b}}{3818}$
Article 10.34.4.1		
$\frac{7.33\times10^7}{(D/t_w)^2}$	10-25	Metric Equivalent Not Given by AASHTO
Article 10.34.4.2		
$\frac{6000\sqrt{k}}{\sqrt{F_y}}$		$\frac{1.52\times10^6\ [1+(D/d_o)^2]}{F_y(D/t_w)^2}$
$\frac{7500\sqrt{k}}{\sqrt{F_y}}$	10-27	Metric Equivalent Not Given by AASHTO
$\frac{4.5\times10^7 k}{(D/t)^2\sqrt{F_y}}$	10-27A	Metric Equivalent Not Given by AASHTO
Article 10.34.4.4		
$\left(0.754-0.34\frac{f_v}{F_v}\right)F_y$	10-29	Metric Equivalent Not Given by AASHTO
Article 10.34.5.2		
$\frac{b'\sqrt{f_b}}{2250}$	10-33	$\frac{b'\sqrt{f_b}}{186.75}$
Article 10.34.6.1 and 10.34.6.2		
$\frac{b'}{12}\sqrt{\frac{F_y}{33\ 000}}$	10-34 10-35	$\frac{b'}{12}\sqrt{\frac{F_y}{227.54}}$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 10.35.1 $\frac{P}{100}\left[\frac{100}{\left(\frac{l}{r}\right)+10}+\frac{\left(\frac{l}{r}\right)F_y}{3\ 300\ 000}\right]$	10-36	$\frac{P}{100}\left[\frac{100}{\left(\frac{l}{r}\right)+10}+\frac{\left(\frac{l}{r}\right)F_y}{22\ 754}\right]$
Article 10.35.2.3 $\frac{1625}{\sqrt{f_a}}$	10-37	$\frac{134.875}{\sqrt{f_a}}$
Article 10.35.2.5 $\frac{4000}{\sqrt{f_a}}$	10-38	$\frac{332}{\sqrt{f_a}}$
Article 10.35.2.7 $\frac{5000}{\sqrt{f_a}}$	10-39	$\frac{415}{\sqrt{f_a}}$
Article 10.35.2.9 $\frac{6000}{\sqrt{f_a}}$	10-40	$\frac{498}{\sqrt{f_a}}$
Article 10.37.2.1 $\frac{5000}{\sqrt{f_a}}$	10-48	$\frac{415}{\sqrt{f_a}}$
Article 10.37.2.2 $\frac{7500}{\sqrt{f_a}}$	10-49	$\frac{622.5}{\sqrt{f_a}}$
Article 10.37.2.3 $\frac{10\,000}{\sqrt{f_a}}$	10-51	$\frac{830}{\sqrt{f_a}}$
Article 10.37.2.4 $\frac{1625}{\sqrt{f_a+\frac{f_b}{3}}}$	10-53	$\frac{134.9}{\sqrt{f_a+\frac{f_b}{3}}}$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 10.37.3.1		
$\frac{4250}{\sqrt{f_a+f_b}}$	10-55	$\frac{352.75}{\sqrt{f_a+f_b}}$
Article 10.37.3.2		
$\frac{1625}{\sqrt{f_a+f_b}}$	10-56	$\frac{134.9}{\sqrt{f_a+f_b}}$
Article 10.38.5.1.2		
$550\left(h+\frac{t}{2}\right)W\sqrt{f'_c}$	10-65	$45.7\times10^{6}\left(h+\frac{t}{2}\right)W\sqrt{f'_c}$
$w^{1.5}(33)\sqrt{f'_c}$	10-67	$w_c^{1.5}(0.042\ 8)\sqrt{f'_c}$
Article 10.39.4.2.1		
$\frac{6140}{\sqrt{F_y}}$	10-72	$\frac{509.62}{\sqrt{F_y}}$
Article 10.39.4.2.2		
$0.224F_y\times\left[1-\sin\left(\frac{\pi}{2}\times\frac{13\ 300-b\frac{\sqrt{F_y}}{t}}{7160}\right)\right]^{0.55F_y-}$	10-73	$0.224F_y\times\left[1-\sin\left(\frac{\pi}{2}\times\frac{1104-b\frac{\sqrt{F_y}}{t}}{594}\right)\right]^{0.55F_y-}$
Article 10.39.4.2.3		
$\frac{13\ 300}{\sqrt{F_y}}$		$\frac{1103.9}{\sqrt{F_y}}$
$57.6\left(\frac{t}{b}\right)^2\times10^6$	10-74	$396\ 854\left(\frac{t}{b}\right)^2$
Article 10.39.4.3.2		
$\frac{3070\sqrt{k}}{\sqrt{F_y}}$	10-76	$\frac{254.810\sqrt{k}}{\sqrt{F_y}}$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 10.39.4.3.4 and 10.39.4.4.4		
$\frac{6650\sqrt{k}}{\sqrt{F_y}}$	10-77	$\frac{551.950\sqrt{k}}{\sqrt{F_y}}$
$0.224F_y \times \left[1-\sin\left(\frac{\pi}{2} \times \frac{6650\sqrt{k}-\frac{w\sqrt{F_y}}{t}}{3580\sqrt{k}}\right)^{0.55F_y-}\right]$		$0.224F_y \times \left[1-\sin\left(\frac{\pi}{2} \times \frac{552\sqrt{k}-\frac{w\sqrt{F_y}}{t}}{297\sqrt{k}}\right)^{0.55F_y-}\right]$
$14.4k\left(\frac{t}{w}\right)^2 \times 10^6$	10-78	$9.94k\left(\frac{t}{w}\right)^2 \times 10^4$
Article 10.39.4.5.1		
$\frac{2600}{\sqrt{F_y}}$	10-87	$\frac{216}{\sqrt{F_y}}$
Article 10.48.1.1		
$\frac{2055}{\sqrt{F_y}}$	10-92	Metric Equivalent Not Given by AASHTO
$\frac{19\ 230}{\sqrt{F_y}}$	10-93	Metric Equivalent Not Given by AASHTO
Article 10.48.2.1		
$\frac{2200}{\sqrt{F_y}}$	10-98	$\frac{182.6}{\sqrt{F_y}}$
$\frac{15\ 400}{\sqrt{F_y}}$	10-99	Metric Equivalent Not Given by AASHTO
$\frac{20\ 000\ 000A_f}{F_y d}$	10-100	$\frac{1.379x10^8 A_f}{F_y d}$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 10.48.4		
$R_b = 1-0.002\left(\frac{D_c t_w}{A_{fc}}\right)\left[\frac{D_c}{t_w}-\frac{\lambda}{\sqrt{M_r / S_{xc}}}\right] \le 1$	10-102b	Metric Equivalent Not Given by AASHTO
$\lambda = 15\ 400$		Metric Equivalent Not Given by AASHTO
$\lambda = 12\ 500$		
$M_r = 91\times10^6\left(\frac{I_{yc}}{L_b}\right)\sqrt{0.772\frac{J}{I_{yc}}+9.87\left(\frac{d}{L_b}\right)^2}$	10-102c	Metric Equivalent Not Given by AASHTO
$\frac{18\ 250}{\sqrt{F_y}}$		Metric Equivalent Not Given by AASHTO
$L_r = \left[\frac{572\times10^6 I_{yc} d}{F_y S_{xc}}\right]^{1/2}$	10-102f	Metric Equivalent Not Given by AASHTO
Article 10.48.5.1		
$\frac{36\ 500}{\sqrt{F_y}}$	10-103	$\frac{3029.5}{\sqrt{F_y}}$
Article 10.48.5.3		
$\frac{2600}{\sqrt{F_y}}$	10-104	Metric Equivalent Not Given by AASHTO
Article 10.48.6.1		
$\frac{73\ 000}{\sqrt{F_y}}$	10-108	$\frac{6059}{\sqrt{F_y}}$
Article 10.48.6.3		
$\frac{d_o\sqrt{F_y}}{23\ 000}$	10-110	$\frac{d_o\sqrt{F_y}}{1909}$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 10.48.8.1		
$V_p\left[C+\frac{0.87(1-C)}{\sqrt{1+(d_o/D)^2}}\right]$	10-113	Metric Equivalent Not Given by AASHTO
$V_p = 0.58F_yDt_w$		Metric Equivalent Not Given by AASHTO
$\frac{6000\sqrt{k}}{\sqrt{F_y}}$		Metric Equivalent Not Given by AASHTO
$\frac{7500\sqrt{k}}{\sqrt{F_y}}$		Metric Equivalent Not Given by AASHTO
$\frac{4.5x10^7(k)}{(Dl_{tw})^2F_y}$	10-116	Metric Equivalent Not Given by AASHTO
Article 10.49.2		
$\frac{18\ 250}{\sqrt{F_y}}$		$\frac{1514.75}{\sqrt{F_y}}$
Article 10.49.3.2		
$\frac{36\ 500}{\sqrt{F_y}}$	10-120	$\frac{3029.5}{\sqrt{F_y}}$
Article 10.50		
$\frac{2200}{\sqrt{1.3f_{dll}}}$	10-121	$\frac{182.6}{\sqrt{1.3f_{dll}}}$
Article 10.51.5.1		
$\frac{6140}{\sqrt{F_y}}$	10-131	$\frac{509.62}{\sqrt{F_y}}$
Article 10.51.5.2		
$\frac{13\ 300}{\sqrt{F_y}}$	10-132	$\frac{1103.9}{\sqrt{F_y}}$
$\frac{13\ 300-\frac{b}{t}\sqrt{F_y}}{7160}$	10-134	$\frac{1103.9-\frac{b}{t}\sqrt{F_y}}{594}$

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 10.51.5.3		
$\frac{13\ 300}{\sqrt{F_y}}$	10-135	$\frac{1103.9}{\sqrt{F_y}}$
$105\left(\frac{t}{b}\right)^2\times10^6$	10-136	$0.724\left(\frac{t}{b}\right)^2\times10^6$
Article 10.51.5.4.1		
$\frac{3070\sqrt{k}}{\sqrt{F_y}}$	10-138	$\frac{254.81\sqrt{k}}{\sqrt{F_y}}$
Article 10.51.5.4.2		
$\frac{6650\sqrt{k}}{\sqrt{F_y}}$	10-139	$\frac{552\sqrt{k}}{\sqrt{F_y}}$
$\frac{6650\sqrt{k}-\frac{w}{t}\sqrt{F_y}}{3580\sqrt{k}}$	10-140	$\frac{552\sqrt{k}-\frac{w}{t}\sqrt{F_y}}{297\sqrt{k}}$
Article 10.51.5.4.3		
$26.2k\left(\frac{t}{w}\right)^2\times10^6$	10-142	$0.181k\left(\frac{t}{w}\right)^2\times10^6$
$\frac{6650\sqrt{k}}{\sqrt{F_y}}$	10-141	$\frac{552\sqrt{k}}{\sqrt{F_y}}$
Article 10.51.5.5		
$\frac{2600}{\sqrt{F_y}}$	10-143	$\frac{215.8}{\sqrt{F_y}}$
Article 10.55.2		
$\frac{6750}{\sqrt{f_a}}$	10-161	$\frac{560}{\sqrt{f_a}}$
$\frac{10\ 150}{\sqrt{f_a}}$	10-162	$\frac{842.5}{\sqrt{f_a}}$
$\frac{13\ 500}{\sqrt{f_a}}$	10-163	$\frac{1121}{\sqrt{f_a}}$
$\frac{2200}{\sqrt{f_s+\frac{f_b}{3}}}$	10-164	Metric Equivalent Not Given by AASHTO

AASHTO EXPRESSIONS (Cont'd)

U.S. Customary	Equation	Metric
Article 10.55.3		
$\frac{5700}{\sqrt{f_a+f_b}}$	10-165	$\frac{473}{\sqrt{f_a+f_b}}$
$\frac{2200}{\sqrt{f_a+f_b}}$	10-166	$\frac{182.6}{\sqrt{f_a+f_b}}$
Article 16.3.4		
$f_u-\left[\frac{f_u^2}{48E}\times\left(\frac{kD}{r}\right)^2\right]$	16-5	$f_u-\left[\frac{f_u^2}{48E}\times\left(\frac{3.28kD}{r}\right)^2\right]$
Article 17.7.4.7		
$\frac{98}{\sqrt[3]{d_c A}}$	17-20	$\frac{17.2}{\sqrt[3]{d_c A}}$

NOMENCLATURE AND UNITS FOR STRUCTURES CALCULATIONS

Symb.	Article	Description	Metric Units	Engl. Units
β_c	8.15.5.6.3	Ratio of long side to short side of concentrated load or reaction area	-	-
β_1	8.16.3.2.2	Ratio of depth of equivalent compression zone to depth from fiber of maximum compressive strain to the neutral axis	-	-
Δ_R	10.15.3	Amount of radial camber?	-	?
λ	10.48.4		-	15400 or 12500
σ_{PL}	3.25.1	Proportional limit stress perpendicular to grain	MPa	psi
ρ	8.15.5.7	Tension reinforcement ratio	-	-
ρ'	8.16.3.4.3	Compression reinforcement ratio	-	-
ρ_f	8.16.3.3.3	???	-	-
ρ_w	8.15.5.2.1	Reinforcement ratio	?	?
ρ_w	8.16.6.2.1	Reinforcement ratio used in Eqns 8-4 and 8-48	-	-
ψ	10.15.2.1	Distance from the outer edge of the tension flange to the neutral axis divided by the depth of the steel section	?	?
A	17.7.4.7	Effective tension area of concrete surrounding the flexural tension reinforcement	mm^2	in^2
A_b	8.25.1	Area of an individual bar	mm^2	in^2
A_f	2.7.4.3	Area of compression flange	mm	in
A_f	10.48.2.1	Area of flange	?	?
A_{fc}	10.48.4	Area of compression flange	-	in^2
A_g	8.15.5.2.2	Gross area of section	mm^2	in^2
A_g	8.16.6.2.2	Gross cross section area	mm^2	in^2
A_w	8.30.1.2	Area of individual wire to be developed or spliced	mm^2	in^2

Symb.	Article	Description	Metric Units	Engl. Units
b	2.7.4.3	Allowable axial stress	MPa	psi
b	8.16.3.3.3	Width of compression face of member	mm	in
b	9.20.2.3	Width of a web of flanged member	m	in
b	10.15.2.1	Widest flange width	mm	in
b	10.39.4.2.2	Flange width between webs	mm	in
b	10.51.5.2	Flange width between webs	mm	in
b'	9.20.2.2	Width of a web of a flanged member	mm	in
b'	10.34.5.2	Width of stiffeners	mm	in
b_f	10.20.2.1	Width of flange	mm	in
b_w	8.16.3.3.3	Web width	mm	in
C	10.48.8.1	Web buckling coefficient	-	-
C_b	Table 10.32.1A	Bending coefficient	-	-
CR_c	9.16.2.1.4	Loss of prestress due to creep of concrete	MPa	psi
d	2.7.4.3	Flange width	mm^2	in^2
d	8.15.5.2.1	Distance from extreme compression fiber to centroid of tension reinforcement.	mm	in
d	9.20.2.2	Distance from extreme compressive fiber to centroid of the prestressing force	m	in
d	9.20.2.3	Distance from extreme compressive fiber to centroid of the prestressing force	m	in
d	Table 10.32.1A	Depth of beam or girder	-	in
d	10.32.4.2	Diameter of rocker or roller	mm	in
d	10.48.2.1	Depth of beam or girder	?	?
d	10.48.4	Depth of beam or girder	-	in
D	9.27.1	Nominal diameter of prestressing steel	mm	in
D	10.15.2.1	Clear distance between flanges	mm	in
D	10.34.3.1.1	Clear unsupported distance between flange components	mm	in
D	10.48.8.1	Clear unsupported distance between flange components	-	?

Symb.	Article	Description	Metric Units	Engl. Units
D	16.3.4	Pipe diameter	mm	in
d'	8.16.3.4.1	Distance from extreme compression fiber to centroid of compression reinforcement	mm	in
d_b	8.25.1	Nominal diameter of bar or wire	mm	in
dc	17.7.4.7	Thickness of concrete cover measured from extreme tension fiber to center of bar or wire located closest thereto	mm	in
D_c	10.48.4	Clear distance between the neutral axis and the compression flange	-	in
d_o	10.48.8.1	Spacing of intermediate stiffener	-	?
E	10.15.3	Modulus of elasticity of steel	-	psi
E	16.3.4	Modulus of Elasticity	MPa	psi
ES	9.16.2.1.4	Loss of prestress due to elastic shortening	MPa	psi
f_a	2.7.4.3	Axial compression stress	MPa	psi
f_a	10.35.2.3	Computed axial compressive stress	MPa	psi
f_b	10.34.2.1.3	Computed compressive bending stress	MPa	psi
f_b	10.34.5.2	Computed compressive bending stress	MPa	psi
f_b	10.37.3.1	Computed compressive bending stress	MPa	psi
F_b	Table 10.32.1A	Allowable bending unit stress	-	psi
f_c'	4.4.12.2	unconfined compressive strength of concrete	MPa	ksi
f_c'	8.7.1	Specified compressive strength of concrete	MPa	psi
f_c'	8.15.5.2.2	Specified compressive strength of concrete	MPa	psi
f_c'	9.20.2.2	Compressive strength of concrete at 28 days	MPa	psi
f_c'	10.38.5.1.2	Unit ultimate compressive strength of concrete as determined by cylinder tests at age of 28 days	MPa	psi
f_{ci}'	9.15.2.1	Compressive strength of concrete at time of initial prestress	MPa	psi
f_{ct}	8.25.2	Average splitting tensile strength of light-weight aggregate concrete	MPa	psi

Symb.	Article	Description	Metric Units	Engl. Units
f_d	9.20.2.2	Stress due to unfactored dead load, at extreme fiber of section where tensile stress is caused by externally applied loads	MPa	psi
F_D	10.20.2.2	Maximum horizontal force	-	?
f_{dll}	10.34.2.1.5	Top flange compressive stress due to noncomposite dead load	MPa	psi
f_{dll}	10.34.2.2.4	Top flange compressive stress due to noncomposite dead load	MPa	psi
f_{dll}	10.50	Top flange compressive stress due to noncomposite dead load	MPa	psi
f_{min}	8.16.8.3	Algebraic minimum stress level in reinforcement	MPa	ksi
f_{pe}	9.20.2.2	Compressive stress in concrete due to effective prestress forces only at extreme fiber of section where tensile stress is caused by externally applied loads	MPa	psi
F_s	10.32.3.3.3	Limiting bending stress	MPa	psi
f_s'	8.16.3.4.3	Stress in compression reinforcement at balanced conditions	MPa	psi
f_{se}	9.17.4.1	Effective steel prestress after losses	MPa	psi
f_{su}^*	9.27.1	Average stress in prestressing steel at ultimate load	MPa	psi
f_{sy}	9.20.3.3	Yield strength of non-prestressed conventional reinforcement in tension	MPa	psi
f_t	10.32.3.3.3	Tensile stress due to applied loads	MPa	ksi
fu	16.3.4	Minimum specified tensile strength	MPa	psi
f_v	10.34.4.4	Unit shear stress	-	psi
F_v	10.34.4.4	Allowable shear stress	-	psi
f_y	8.16.3.2.2	Specified yield strength of reinforcement	MPa	psi
F_y	2.7.4.3	Minimum yield stress	MPa	psi
F_y	10.15.2.1	Specified minimum yield point of steel	MPa	psi
F_y	10.34.4.2	Specified minimum yield stress of steel	-	psi

Symb.	Article	Description	Metric Units	Engl. Units
F_y	10.39.4.2.1	Specified minimum yield point of steel	MPa	psi
h	2.7.4B	Height of top of rail above reference surface	m	in
h	8.16.8.3	overall thickness of member	mm	in
h	10.38.5.1.2	Average flange thickness of the channel flange	m	in
I_{yc}	Table 10.32.1A	Moment of inertia of compression flange about the vertical axis in the plane of the web	-	in^4
J	Table 10.32.1A	St. Venont torsional constant	-	in^4
J	10.48.4	St. Venont torsional constant	-	in^4
k	10.34.4.2	Buckling coefficient	?	?
k	10.39.4.3.2	Buckling coefficient	-	-
k	10.51.5.4.1	Buckling coefficient	-	-
k	16.3.4	Parameter dependent on the value of the friction angle	-	-
K	Table 10.32.1A	Effective length factor in plane of buckling	-	-
K	3.25.1	Wheel load distribution constant for timber flooring	-	-
l	10.35.1	Member length	mm	in
l	Table 10.32.1A	Member length	-	in
l_x	9.17.4.2	Distance from end of prestressing strand to center of panel	mm	in
L	3.14.1	Loaded length of sidewalk	m	ft
L	10.20.2.1	Span length	m	ft
L	Table 10.32.1A	Actual unbraced length	m	ft
L	3.8.2	Loaded length of span	m	ft
L	10.15.3	Actual unbraced length	-	?
L_b	10.48.4	Unbraced length	-	in
L_r	10.48.4	Limiting unbraced length	-	in
M	8.15.5.2.1	Design moment occurring simultaneously with V at the section being considered	Nm	inlb

Symb.	Article	Description	Metric Units	Engl. Units
M_{cb}	10.20.2.1	????	Nm	ftlb
M_{cr}	9.20.2.2	Moment causing flexural cracking at section due to externally applied loads	Nm	inlb
M_D	3.25.1	Moment capacity	Nm	inlb
M_{max}	9.20.2.2	Maximum factored moment at section due to externally applied loads	Nm	inlb
M_r	10.48.4	Moment carrying capacity of member	-	inlb
M_u	8.16.6.2.1	Factored moment at section	Nm	inlb
M_y	3.25.1	Total secondary moment transferred	Nm	inlb
N	8.15.5.2.3	Design axial load normal to cross section occurring simultaneously with V	N	lb
N_u	8.16.6.2.2	Factored axial load normal to the cross section occurring simultaneously with Vu	N	lb
P	3.25.1	Design wheel load	N	lb
P	10.32.4.2	Allowable bearing	MN/m	lb/in
P	10.35.1	Allowable compressive axial load on members	N	lb
$P_{13.5}$	3.24.3	13500	-	-
P_{18}	3.24.3	18000	-	-
r	8.16.8.3	Radius of gyration of cross section of a compression member	mm	in
r	Table 10.32.1A	Radius of gyration	m	in
r	10.35.1	Radius of gyration	mm	in
r	16.3.4	Radius of gyration	mm/m	in/ft
R	3.10	Radius of curve	m	ft
R_b	10.48.4	Bending capacity reduction factor	-	-
R_D	3.25.1	Shear capacity	N	lb
RH	9.16.2.1.1	Mean annual ambient relative humidity	%	%
R_y	3.25.1	Total secondary shear transferred	N	lb
s	3.25.1	Effective deck span	m	in

Symb.	Article	Description	Metric Units	Engl. Units
s	8.19.1.2	Spacing of shear reinforcement in direction parallel to the longitudinal reinforcement	mm	in
S	3.24.3	Effective span length	m	ft
S	3.24.10.2	Effective span length	m	ft
S	3.10	Design speed	km/h	mi/h
S_d	10.20.2.1	Diaphragm spacing	m	ft
SH	9.16.2.1.4	Loss of prestress due to concrete shrinkage	MPa	psi
s_w	8.30.1.2	Spacing of wires to be developed or spliced	mm	in
S_{xc}	Table 10.32.1A	Section modulus with respect to the compression flange	-	in^3
t	10.38.5.1.2	Thickness of a web of a channel	m	in
t	10.39.4.2.2	Flange thickness	mm	in
t	10.51.5.2	Flange thickness	mm	in
t_f	10.20.2.1	Thickness of flange	m	in
t_w	10.15.2.1	Web thickness	mm	in
t_w	10.48.2.1	Web thickness	mm	in
V	8.15.5.2.1	Shear design force at section	N	lb
V_d	9.20.2.2	Shear force at section due to unfactored dead load	N	lb
V_i	9.20.2.2	Factored shear force at section due to externally applied loads occurring simultaneously with M_{max}	N	lb
V_p	9.20.2.3	Vertical component of effective prestress force at section	N	lb
V_u	8.16.6.2.1	Factored shear force at section	N	lb
W	10.20.2.1	Wind loading along the exterior flange	-	lb/ft
W	10.38.5.1.2	Length of a channel shear connector	m	in
w	10.39.4.3.4	Width of flange between longitudinal stiffeners	mm	in
w	10.51.5.4.2	Width of flange between longitudinal stiffeners	mm	in

Symb.	Article	Description	Metric Units	Engl. Units
W	3.14.1	Width of sidewalk	m	ft
w_c	8.7.1	Weight of concrete	kg/m^3	lbs/ft^3
X	3.24.5.1	Distance from load to point of support	m	ft
Yield pt of steel	10.25.3	Yield point of steel	MPa	psi
Y_o	10.15.3	Distance from neutral axis to the extreme outer fiber	-	in
Y_t	9.20.2.2	Distance from centroidal axis of gross section to extreme fiber in tension	mm	in

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CHAPTER FIVE

Materials

The following standards are given as recommendations to the conversion of Materials activities to the metric system.

- The Materials Manual must be converted to metric units for use on pilot projects for 1994 and general use in 1995.
- All equipment must be calibrated using metric units.
- All existing and new software programs must be able to accommodate metrication.
- Programs written specifically for materials testing must be modified to accommodate metrication with the assistance of Information Systems personnel.

UNITS

Quantity	Unit	Symbol
length	millimeter meter kilometer	mm m km
area	square millimeter square meter	mm^2 m^2
volume	liter cubic meter	L m^3
mass	gram kilogram metric ton	g kg t
temperature	degree Celsius	°C

STRUCTURAL STEEL

The American Institute of Steel Construction has available their publication "Metric Properties of Structural Shapes with Dimensions According to ASTM A6M," the metric version of Part 1 of the Manual of Steel Construction. This publication basically provides a soft conversion for all conventional U.S. measurements for structural steel shapes to metric units.

There are three dominant world steel shape standards:

1. ASTM A6/A6M, American
2. JIS, Japanese Industrial Standard
3. DIN, Deutsches Instituet fuer Normung, (German)

A fourth is the BI, or British Imperial. None is dominant worldwide, but each is used extensively. There is no international standard issued by ISO (International Standards Organization), the official international group that develops worldwide standards.

The ISO standard is currently undergoing development, and will probably involve selection of shapes from the three primary world standards, coupled with elimination of redundant shapes.

Since no international trend exists on standardization of steel shapes, AISC recommends that metric projects use the same steel shapes currently used, only use the metric dimensions listed in ASTM A6/A6M. A6/A6M lists both inch and mm dimensions of the shapes. All LRFD property, shape, and specification design data is available in metric from AISC for A6/A6M steel shapes (Phone orders: AISC, Chicago, IL, 312-670-5414). Structural calculations should be done in metric.

Fasteners

- Large projects must use ASTM A325, A490, and A615 metric bolts. The primary benefit of using these new sizes is that there is a reduction in the number of bolts, from nine to seven. Standard sizes are: 16, 20, 22, 24, 27, 30 and 36 mm. The Bridge Bureau does not currently use 27, 30 and 36 mm bolts. 24 mm bolts can be used with the Bridge Engineer's approval.

Fasteners (Cont.)

Metric Bolt Designation	Diameter mm (in.)	English Substitution
M16	16 (0.63)	5/8
M20	20 (0.79)	-
M22	22 (0.87)	7/8
M24	24 (0.94)	-
M27	27 (1.06)	1 1/8
M30	30 (1.18)	1 1/4
M36	36 (1.42)	-

Many firms can make the hard metric sizes. Minimum order quantities may apply for a period of time. Until these products become standard, verify that your project has sufficient quantity to meet minimum requirements.

Standard Hole Diameters					
Bolts		Holes		M-Bolts	Holes
mm	(in.)	mm	(in.)	mm	mm
12.7	1/2	14.3	9/16	-	-
15.9	5/8	17.5	11/16	M16	18
19.0	3/4	20.6	13/16	-	-
-	-	-	-	M20	22
22.2	7/8	23.8	15/16	M22	24
-	-	-	-	M24	26
25.4	1	27.0	1-1/16	-	-
28.6	1 1/8	30.2	1-3/16	M27	30
31.8	1 1/4	33.3	1-5/16	M30	33
34.9	1 3/8	36.5	1-7/16	-	-
-	-	-	-	M36	39
38.1	1 1/2	39.7	1-9/16	-	-

STEEL FABRICATION

Many firms have the capability of fabricating steel from metric design drawings. Two of these firms are:

Havens Steel, Kansas City, MO (Contact: 816-231-5724).
Steelco Div., Metropolitan Steel, Sinking Spring, PA (Contact: Ron Keating, 215-678-6411).

REINFORCING STEEL

Metric projects will use ASTM A615M reinforcing bars, which come in Grades 300 and 400 (indicating 300 and 400 MPa yield strengths), for general purpose applications. Metric rebars vary based on round values of cross-sectional area, which are specified by nominal diameter at 5 mm increments. There are 8 bar sizes, which replace the 11 bar sizes currently being used. While many firms can make metric rebar, minimum order quantities apply. It should be determined for each project if metric rebar is feasible, or if existing sizes should be used.

The following table shows the available metric rebar sizes and the current U.S. customary rebar sizes in relationship to the respective diameters and cross-sectional areas.

Metric Bar Designation	U.S. Customary Designation	Customary English System		Metric Equivalent	
		Diameter (in.)	Area ($in.^2$)	Diameter (mm)	Area (mm^2)
	#3	0.375	0.11	9.5	71
10				11.3	100
	#4	0.500	0.20	12.7	127
	#5	0.625	0.31	15.9	198
15				16.0	200
	#6	0.750	0.44	19.1	285
20				19.5	300
	#7	0.875	0.60	22.2	388
25				25.2	500
	#8	1.000	0.79	25.4	507
	#9	1.125	1.00	28.6	641
30				29.9	700
	#10	1.270	1.27	32.3	817
35				35.7	1000

Metric Bar Designation	U.S. Customary Designation	Customary English System		Metric Equivalent	
		Diameter (in.)	Area ($in.^2$)	Diameter (mm)	Area (mm^2)
	#11	1.410	1.56	35.8	1007
	#14	1.693	2.25	43.0	1452
45				43.7	1500
55				56.4	2500
	#18	2.257	4.00	57.3	2579

STEEL PLATE

Metric Value (mm)	English Equivalent (in.)
5	0.196 9
5.5	0.216 5
6	0.236 2
7	0.275 6
8	0.315 0
9	0.354 3
10	0.393 7
11	0.433 1
12	0.472 4
14	0.551 2
16	0.629 9
18	0.708 7
20	0.787 4
22	0.866 1
25	0.984 3
28	1.102 4
30	1.181 1
32	1.259 8

Metric Value (mm)	English Equivalent (in.)
35	1.378 0
38	1.496 1
40	1.574 8
45	1.771 7
50	1.968 5
55	2.165 4
60	2.362 2

NOTE: Over 60 mm up to 200 mm increase in 10 mm increments, and over 200 mm in 50 mm increments (Based on ANSI Standard B323)

SHEET METAL

Most specification references use gage number followed by the decimal inch thickness.

Example: 22 gage (0.033 6 inch)

Metric specifications use the absolute millimeter thickness. It is not the intent of this guidance to change the thickness of currently used sheeting.

The following chart may be used to specify sheet metal. The thickness under "Specify" is thinner than the actual gage thickness, since specifications give minimum thickness.

Gage	Inch	Exact (mm)	Specify (mm)	Percent Thinner Than "Exact" Value
32	0.013 4	0.340 4	0.34	0.1
30	0.015 7	0.398 8	0.39	2.2
28	0.018 7	0.475 0	0.47	1.1
26	0.021 7	0.551 2	0.55	0.2
24	0.027 6	0.701 0	0.70	0.1
22	0.033 6	0.853 4	0.85	0.4
20	0.039 6	1.005 8	1.0	0.6
18	0.051 6	1.310 6	1.3	0.8
16	0.063 5	1.612 9	1.6	0.8

Gage	Inch	Exact (mm)	Specify (mm)	Percent Thinner Than "Exact" Value
14	0.078 5	1.993 9	1.9	4.7
12	0.108 4	2.753 4	2.7	1.9
10	0.138 2	3.510 3	3.5	0.3
8	0.168 1	4.269 7	4.2	1.6

This schedule was developed since no existing material was found to clearly identify existing sheeting in metric units. Until a more efficient method is developed to address this issue, specifiers may wish to retain the gage number in specifications, and couple this with a rounded millimeter size in parenthesis.

STEEL WIRE STRAND

Mechanical Properties of Stainless and Heat-Resisting Steel Wire Strand					
Nominal Diameter of Strand, mm (in.)	Number of Wires in Strand	Nominal Diameter of Stainless Wires, mm (in.)	Approx. Weight of Strand per 304.8 m (1000 ft.), kg (lb)	Minimum Breaking Strength of Strand kN (lbf)	
				Medium Strength	High Strength
5.16 (13/64)	3	2.36 (0.093)	32.66 (72)	14.01 (3150)	20.02 (4500)
5.56 (7/32)	3	2.64 (0.104)	40.82 (90)	17.57 (3950)	25.13 (5650)
6.35 (¼)	3	3.05 (0.120)	54.43 (120)	23.58 (5300)	33.58 (7550)
7.94 (5/16)	3	3.68 (0.145)	79.38 (175)	34.25 (7700)	48.93 (11 000)
9.52 (⅜)	3	4.19 (0.165)	102.06 (225)	44.48 (10 000)	63.61 (14 300)
5.56 (7/32)	7	1.83 (0.072)	45.36 (100)	20.02 (4500)	28.02 (6300)
6.35 (¼)	7	2.11 (0.083)	59.87 (132)	26.47 (5950)	37.81 (8500)
7.14 (9/32)	7	2.36 (0.093)	75.75 (167)	32.69 (7350)	46.71 (10 500)
7.94 (5/16)	7	2.64 (0.104)	94.35 (208)	40.92 (9200)	58.72 (13 200)
9.52 (⅜)	7	3.05 (0.120)	126.10 (278)	55.60 (12 500)	80.07 (18 000)
11.11 (7/16)	7	3.68 (0.145)	183.71 (405)	80.96 (18 200)	115.65 (26 000)
12.70 (½)	7	4.19 (0.165)	238.14 (525)	104.98 (23 600)	149.90 (33 700)
9.52 (⅜)	19	1.90 (0.075)	133.81 (295)	52.49 (11 800)	74.73 (16 800)
11.11 (7/16)	19	2.21 (0.087)	181.44 (400)	70.28 (15 800)	100.08 (22 500)
12.70 (½)	19	2.54 (0.100)	240.40 (530)	93.41 (21 000)	133.45 (30 000)
14.29 (9/16)	19	2.79 (0.110)	290.30 (640)	112.98 (25 400)	161.02 (36 200)

Mechanical Properties of Stainless and Heat-Resisting Steel Wire Strand					
Nominal Diameter of Strand, mm (in.)	Number of Wires in Strand	Nominal Diameter of Stainless Wires, mm (in.)	Approx. Weight of Strand per 304.8 m (1000 ft.), kg (lb)	Minimum Breaking Strength of Strand kN (lbf)	
				Medium Strength	High Strength
15.88 (5/8)	19	3.18 (0.125)	374.21 (825)	146.79 (33 000)	209.07 (47 000)
19.05 (3/4)	19	3.81 (0.150)	539.78 (1190)	211.29 (47 500)	300.25 (67 500)
22.22 (7/8)	19	4.44 (0.175)	734.82 (1620)	284.69 (64 000)	406.57 (91 400)

NOTE: The diameter of the individual wires forming the strand shall not vary from the nominal wire diameters by more than ± 0.025 mm (± 0.001 in.).

SEVEN-WIRE, UNCOATED STRAND FOR PRESTRESSED CONCRETE STRUCTURES

The prestressing industry again uses the soft conversion for all dimensional units of prestressing wire. This soft conversion is utilized worldwide and a copy of the equivalent physical properties for Grade 270 low-relaxation strand, as provided by Florida Wire and Cable Company, is provided below.

270 GRADE LOW-RELAXATION ASTM A-416					
Nominal Strand Diameter		**Minimum Strength**		**Area**	
(mm)	**(in.)**	**(kN)**	**(lb.)**	**(mm^2)**	**(in^2)**
10	(3/8)	102.3	(23 000)	54.8	(0.085)
11	(7/16)	137.9	(31 000)	74.2	(0.115)
12	(15/32)	160.1	(36 000)	85.8	(0.133)
13	(½)	183.7	(41 300)	98.7	(0.153)
14	(9/16)	230.0	(51 700)	123.9	(0.192)
15	(0.600)	260.6	(58 600)	140.0	(0.217)

CONCRETE

Concrete strength is specified in megapascals (MPa). The following strengths are standard in federal metric construction. The general purpose concrete strengths are reduced from 6 strengths to 4 strengths.

Strengths above 35 MPa shall be specified in 5 MPa intervals (40, 45, 50, 55, etc.).

Metric Value (MPa)	English Value (psi)	Specify (MPa)
17.23	2500	20
20.67	3000	20 or 25*
24.12	3500	25
27.56	4000	30
31.01	4500	35
34.45	5000	35

* If code requires 3000 psi, then 25 MPa must be used, otherwise it is a professional judgement on 20 or 25.

SIEVES

(From Modified AASHTO M92-85 and MDT Materials Manual MT 405)

Sieve Designation, (W)		Nominal Sieve Opening (in.)[C]	Permissible Variation of Average Opening from the Standard Sieve Designation (y)	Intermediate Tolerance (z)[G]	Maximum Individual Opening (x)	Nominal Wire Diameter (mm[A])
Standard[B]	Alternative					
125 mm	5 in.	5	±3.70 mm	130.0 mm	130.9 mm	8.00
106 mm	4.24 in.	4.24	±3.20 mm	110.2 mm	111.1 mm	6.40
100 mm[D]	4 in.[D]	4	±3.00 mm	104.0 mm	104.8 mm	6.30
90 mm	3½ in.	3.5	±2.70 mm	93.6 mm	94.4 mm	6.08
75 mm	3 in.	3	±2.20 mm	78.1 mm	78.7 mm	5.80
63 mm	2½ in.	2.5	±1.90 mm	65.6 mm	66.2 mm	5.50
53 mm	2.12 in.	2.12	±1.60 mm	55.2 mm	55.7 mm	5.15
50 mm[D]	2 in.[D]	2	±1.50 mm	52.1 mm	52.6 mm	5.05
45 mm	1¾ in.	1.75	±1.40 mm	46.9 mm	47.4 mm	4.85
37.5 mm	1½ in.	1.5	±1.10 mm	39.1 mm	39.5 mm	4.59
31.5 mm	1¼ in.	1.25	±1.00 mm	32.9 mm	33.2 mm	4.23
26.5 mm	1.06 in.	1.06	±0.80 mm	27.7 mm	28.0 mm	3.90
25.0 mm[D]	1 in.[D]	1	±0.80 mm	26.1 mm	26.4 mm	3.80
22.4 mm	⅞ in.	0.875	±0.70 mm	23.4 mm	23.7 mm	3.50
19.0 mm	¾ in.	0.750	±0.60 mm	19.9 mm	20.1 mm	3.30
16.0 mm	⅝ in.	0.625	±0.50 mm	16.7 mm	17.0 mm	3.00
13.2 mm	0.530 in.	0.530	±0.41 mm	13.83 mm	14.05 mm	2.75
12.5 mm[D]	½ in.[D]	0.500	±0.39 mm	13.10 mm	13.31 mm	2.67
11.2 mm	7/16 in.	0.438	±0.35 mm	11.75 mm	11.94 mm	2.45
9.50 mm	⅜ in.	0.375	±0.30 mm	9.97 mm	10.16 mm	2.27
8.00 mm	5/16 in.	0.312	±0.25 mm	8.41 mm	8.58 mm	2.07
6.70 mm	0.265 in.	0.265	±0.21 mm	7.05 mm	7.20 mm	1.87
6.30 mm[D]	¼ in.[D]	0.250	±0.20 mm	6.64 mm	6.78 mm	1.82
5.60 mm	No. 3½[E]	0.223	±0.18 mm	5.90 mm	6.04 mm	1.68
4.75 mm	No. 4	0.187	±0.15 mm	5.02 mm	5.14 mm	1.54
4.00 mm	No. 5	0.157	±0.13 mm	4.23 mm	4.35 mm	1.37
3.35 mm	No. 6	0.132	±0.11 mm	3.55 mm	3.66 mm	1.23
2.80 mm	No. 7	0.111	±0.095 mm	2.975 mm	3.070 mm	1.10

[A] The average diameter of the warp and of the shoot wires, taken separately, of the cloth of any sieve shall not deviate from the nominal values by more than the following:
Sieves coarser than 600 μm → 5% Sieves 600 to 125 μm → 7½% Sieves finer than 125 μm → 10%

[B] These standard designations correspond to the values for test sieve apertures recommended by the International Standards Organization, Geneva, Switzerland.

[C] Only approximately equivalent to the metric values in Column 1.

[D] These sieves are not in the standard series, but they have been included because they are in common usage.

[E] These numbers (3½ to 635) are the approximate number of openings per linear in., but it is preferred that the sieve be identified by the standard designation in mm or μm.

[F] 1000 μm - 1 mm.

[G] Not more than 5% of the openings may fall between the limits set by the values in Column 5 and Column 6.

SIEVES (Cont.)

Sieve Designation, (W)		Nominal Sieve Opening (in.)[C]	Permissible Variation of Average Opening from the Standard Sieve Designation (y)	Intermediate Tolerance (z)[G]	Maximum Individual Opening (x)	Nominal Wire Diameter (mm[A])
Standard[B]	Alternative					
2.36 mm	No. 8	0.093 7	±0.080 mm	2.515 mm	2.600 mm	1.00
2.00 mm	No. 10	0.078 7	±0.070 mm	2.135 mm	2.215 mm	0.900
1.70 mm	No. 12[E]	0.066 1	±0.060 mm	1.820 mm	1.890 mm	0.810
1.40 mm	No. 14	0.055 5	±0.050 mm	1.505 mm	1.565 mm	0.725
1.18 mm	No. 16	0.046 9	±0.045 mm	1.270 mm	1.330 mm	0.650
1.00 mm	No. 18	0.039 4	±0.040 mm	1.080 mm	1.135 mm	0.580
850 μm[F]	No. 20	0.033 1	±35 μm	925 μm	970 μm	0.510
710 μm	No. 25	0.027 8	±30 μm	775 μm	815 μm	0.450
600 μm	No. 30	0.023 4	±25 μm	660 μm	695 μm	0.390
500 μm	No. 35	0.019 7	±20 μm	550 μm	585 μm	0.340
425 μm	No. 40	0.016 5	±19 μm	471 μm	502 μm	0.290
355 μm	No. 45	0.013 9	±16 μm	396 μm	425 μm	0.247
300 μm	No. 50	0.011 7	±14 μm	337 μm	363 μm	0.215
250 μm	No. 60	0.009 8	±12 μm	283 μm	306 μm	0.180
212 μm	No. 70	0.008 3	±10 μm	242 μm	263 μm	0.152
180 μm	No. 80	0.007 0	±9 μm	207 μm	227 μm	0.131
150 μm	No. 100	0.005 9	±8 μm	174 μm	192 μm	0.110
125 μm	No. 120	0.004 9	±7 μm	147 μm	163 μm	0.091
106 μm	No. 140	0.004 1	±6 μm	126 μm	141 μm	0.076
90 μm	No. 170	0.003 5	±5 μm	108 μm	122 μm	0.064
75 μm	No. 200	0.002 9	±5 μm	91 μm	103 μm	0.053
63 μm	No. 230	0.002 5	±4 μm	77 μm	89 μm	0.044
53 μm	No. 270	0.002 1	±4 μm	66 μm	76 μm	0.037
45 μm	No. 325	0.001 7	±3 μm	57 μm	66 μm	0.030
38 μm	No. 400	0.001 5	±3 μm	48 μm	57 μm	0.025
32 μm	No. 450	0.001 2	±3 μm	42 μm	50 μm	0.028
25 μm[D]	No. 500	0.001 0	±3 μm	34 μm	41 μm	0.025
20 μm[D]	No. 635	0.000 8	±3 μm	29 μm	35 μm	0.020

[A] The average diameter of the warp and of the shoot wires, taken separately, of the cloth of any sieve shall not deviate from the nominal values by more than the following:
Sieves coarser than 600 μm → 5% Sieves 600 to 125 μm → 7½% Sieves finer than 125 μm → 10%

[B] These standard designations correspond to the values for test sieve apertures recommended by the International Standards Organization, Geneva, Switzerland.

[C] Only approximately equivalent to the metric values in Column 1.

[D] These sieves are not in the standard series, but they have been included because they are in common usage.

[E] These numbers (3½ to 635) are the approximate number of openings per linear in., but it is preferred that the sieve be identified by the standard designation in mm or μm.

[F] 1000 μm - 1 mm.

[G] Not more than 5% of the openings may fall between the limits set by the values in Column 5 and Column 6.

HARD CONVERSIONS FOR CONSTRUCTION MATERIALS

Structural Steel, M270			
Grade	Min. Tensile Strength (MPa)	Min. Yield Strength (MPa)	Min. Yield Strength (ksi)
36	400	250	36
50	450	345	50
50W	485	345	50
70W	620	480	70

Reinforcing Bars, M31M				
Grade		Tensile and Yield Strengths		
Metric Value	English Value	Tensile Strength (MPa)	Min. Yield Strength (MPa)	Min. Yield Strength (ksi)
300	40	500	300	40
400	60	600	400	60

Common Concrete Strengths (f_c')							
Metric (MPa)	21	24	28	35	42	48	55
English (psi)	3000	3500	4000	5000	6000	7000	8000

Coefficient of Thermal Expansion		
	Metric Value	English Value
Steel	0.000 011 7/°C	0.000 006 5/°F
Concrete	0.000 010 8/°C	0.000 006/°F

Unit Weights		
	Metric Value	English Value
Steel	7848.3 kg/m^3	490 pcf
Concrete	2402.5 kg/m^3	150 pcf

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CHAPTER SIX

Traffic

Most of the applications of interest are conversions associated with measurements found in the *Manual on Uniform Traffic Control Devices* (MUTCD). These values include sign sizes, pavement marking widths, traffic signal lens size, etc. Please note that the following values are recommendations only.

UNITS

Quantity	Unit	Symbol
length	millimeter meter kilometer	mm m km
area	square meter	m^2
volume	liter cubic meter	L m^3
mass	metric ton	t

SIGN CONVERSION VALUES

This list will not be exhaustive, but the principles set out should allow conversion of any value encountered.

Dimension in inches x 25 = millimeters

Typical metric sign sizes
300 mm
450 mm
600 mm
750 mm
900 mm
1050 mm
1200 mm
1350 mm
1500 mm

The difference between a hard conversion (1 inch = 25 mm) and a soft conversion (1 inch = 25.4 mm) is only 1.6 percent.

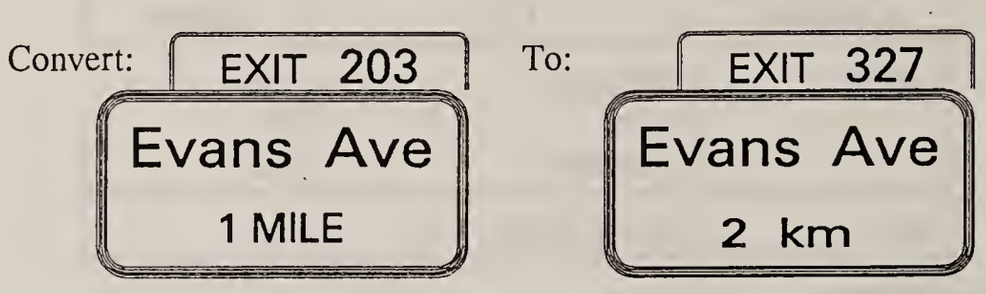
SIGN CONVERSION TECHNIQUES

Depending on the type of sign mounting (ground mounted versus overhead mounted), the condition of the sign, the location of the sign, and the degree of legend alteration required for metric conversion, different conversion techniques are appropriate as described in the following explanations.

Signs Mounted Overhead on Bridges, Trusses, and Cantilever Supports

For signs mounted overhead on bridges, trusses, and cantilever supports, the following techniques are available:

- **Partial Overlay** A partial overlay is the quickest, easiest, and cheapest sign conversion technique and is appropriate if the sign panel is otherwise in good condition and only a small portion of the panel needs to be changed. A good example for the use of a partial overlay is as follows:



- **Replace Panel** - replacement will probably be required if the existing panel is in poor condition (letters peeling, defaced, bent, etc.), if the new metric legend is too large to allow simple overlaying, or if "non-preferred" sign materials are encountered (raised metallic letters, raised buttons for reflectivity, etc.). Replacing the panel is more expensive in materials, equipment, and labor. A crane is needed to remove the old panel and to hoist the new panel into place, which not only increases costs but also disrupts traffic flow for a longer period of time requiring more sophisticated work zone protection methods.

- **Complete Overlay** (Using an aluminum panel that is pop riveted to the old sign panel) - This alternative to replacing the panel speeds up installation since it is not necessary to remove the old panel. It also has a lower material cost since the thickness of the aluminum sign panel that is required for overlaying is less than for sign panel replacement.

Ground Mounted Signs

For ground mounted signs, the following techniques are applicable:

- **Partial Overlay** - Partially overlaying large ground mounted signs has the same basic characteristics as partially overlaying overhead mounted signs. However, for small inexpensive ground mounted signs, such as speed limit signs and warning signs, it is often just as easy to completely replace the sign.

SIGN CONVERSION TECHNIQUES (Cont.)

Ground Mounted Signs (Cont.)

- **Replace Panel or Complete Overlay** - panel replacements or complete overlays are easier for ground mounted signs than for overhead signs since it is not necessary to work high above the roadway. This is also less expensive and simplifies work zone traffic controls.

- **Replace Supports** - If the sign supports are defective (slip base buried, hinges installed backwards, etc.), yet the sign panel is in good shape replace the support. The appropriate portion of the legend can be overlaid, and the sign panel reinstalled on new supports. This is less expensive than installing an entirely new sign and scrapping the old one.

- **Replace Entire Sign Installation** - If both the supports and legend are substandard, the sign will need to be replaced.

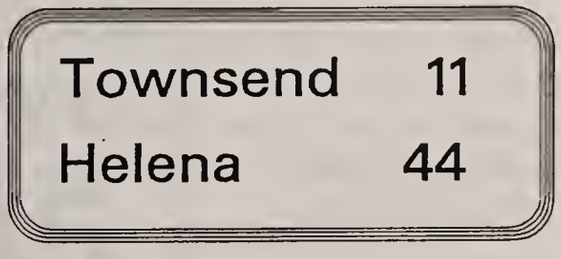
Depending on the situation at hand, we can expect to use most of these techniques during the metric conversion process.

BASIC SIGN TYPES

Before discussing the various design issues that are associated with metric sign conversion it is of value to identify and discuss the various types of metric distance and speed signs that are typically encountered.

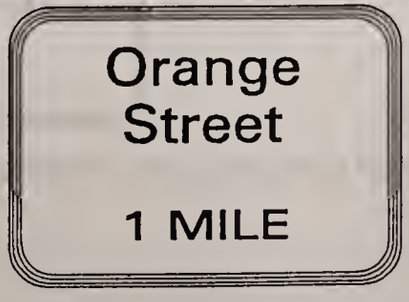
Destination Signs

For Example:



Advance Guide Signs (<u>without</u> exit numbering)

For Example:



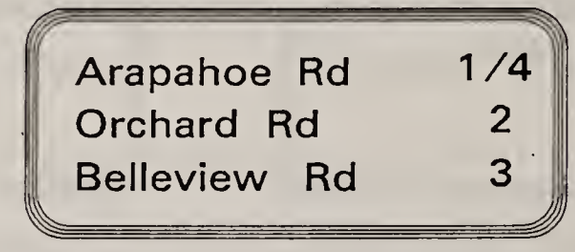
Advance Guide Signs (with exit numbering)

For Example:

These are typically larger freeway signs with some of them being mounted overhead, especially along urban Interstate areas. Since the bottom line of the sign is usually totally devoted to the distance, the "Exit 1 Mile" or "1 Mile" legend can be easily overlaid with an equivalent metric legend such as "Exit 2 km" or "2 km".

Interchange Sequence Signs

For Example:

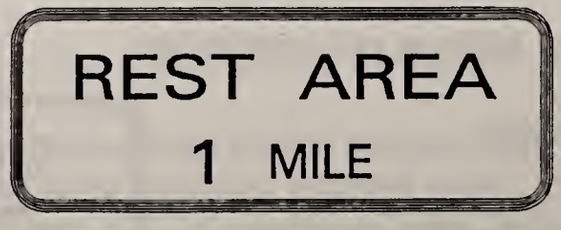


These signs are almost exclusively encountered on urban Interstate areas. They are typically situated on an overhead structure. Whether or not a partial overlay can be used depends on the relative sizes of the new metric legend and the existing English legend. For example, we would like to overlay the "1/4" in the above sign with "400 m", the "2" with "3 km" and the "3" with "5 km", however, there may not be enough room to do so.

If there is insufficient room for a partial overlay, a complete overlay may be needed with abbreviations used or the "Ave", "St", "Blvd" and "Rd" words eliminated. If at all possible, we will want to avoid having to use a larger sign panel which could require expensive modification of the support structure. Abbreviations used should conform to standard practice and requirements of the MUTCD.

Advance Rest Area/Service Center Signs (usually white on blue)

For Example:



These are freeway signs that lend themselves well to a partial overlay.

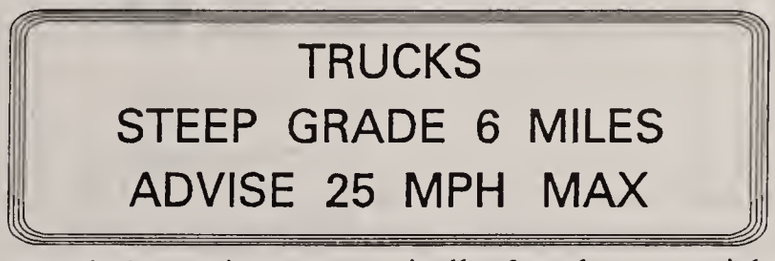
BASIC SIGN TYPES (Cont.)

Warning Signs (black on yellow, diamond-shaped with supplemental plaque)

For Example:

Or rectangular in shape with special message.

For Example:



The smaller black on yellow diamond shape signs are typically found on arterials and, because of their small size, are good candidates for complete replacement. The larger special warning signs are typically found on freeways, with some of them being mounted overhead. These larger signs are fitting candidates for a partial overlay.

Standard Speed Limit Signs

For Example:

Given their relatively small size, complete replacement is appropriate for these signs.

School Speed Limit Signs (Ground Mounted)

For Example:

Given their relatively small size, complete replacement is appropriate for these signs.

Ramp/Exit Speed Signs

For Example:

Given their relatively small size, complete replacement is appropriate for these signs.

BASIC SIGN TYPES (Cont.)

Advisory Speed Plates (Black on Yellow - these signs are typically found in the form of supplemental plaques located below diamond shaped warning signs)

For Example:

Given their relatively small size, complete replacement of the supplemental plaque is appropriate for those signs.

Miscellaneous Signs (Anything that does not fit into the previous categories would be classified here. This includes minor directional signs which provide distance information for locations of interest such as parks, hospitals, post offices, etc.)

Conversion method will vary by type of sign, but typically will involve complete replacement.

DESIGN ISSUES

There are a number of important design issues that must be considered in converting signs to the metric system. These issues are discussed below:

Issue 1: Dualization

Dualization refers to the use of both English units and metric units to convey the same information. Dualization may involve the use of English and metric units on the same sign panel, on separate sign panels at the same location, or on separate signs in the same general area. Another form of dualization involves special "Metric equivalence" signs. These signs provide general information that allows motorists to convert from English units to metric units.

DESIGN ISSUES (Cont.)

Issue 1: Dualization (Cont.)

Dualization often requires a larger sign to handle the expanded legend, which necessitates the complete replacement of the sign panel rather than the use of inexpensive overlays. The use of a larger sign panel may, in turn, require the use of larger supports. In the case of overhead signs, the entire support structure will need to be analyzed and may need to be replaced or strengthened. The additional cost associated with dualization can be substantial.

If speeds or distances are rounded then dual legend signs can lead to confusing comparisons. For example, a distance sign that is rounded to the nearest kilometer might have the legend "Butte 1 mi 2 km", giving the indication that a mile equals 2 kilometers when a mile actually equals 1.6 kilometers.

Dualization complicates the sign legend, making it more difficult for a motorist to read and comprehend. A strong argument can also be made that dualization will allow U.S. motorists to ignore the metric portion of the legend, concentrating instead on the portion of the legend with English units. The end result will be that U.S. motorists will not "acquire a feel" for metric speeds and distances, as they would if they were forced to rely on pure metric signs.

At some point dualization would have to give way to a pure metric system. When this happens, there would be an additional cost to modify the sign legends in order to eliminate the English units.

Finally, the FHWA is recommending that states avoid dualization of measurements beyond FY 1993, unless it is determined that such usage will be beneficial.

For all of those reasons we are recommending that dualization <u>not</u> be used in Montana's metric conversion.

The exception is in the case of load limit signs and vertical clearance signs where the use of dualization for a period of five years will be advocated.

Issue 2: Hard Versus Soft Conversions

A "soft" conversion is a direct conversion with little or no rounding. For example, using a soft conversion approach 1 mile would become 1.6 kilometers and *55* mph would become 88 km/h. On the other hand, a "hard" conversion uses rounding to obtain values that are in even increments. Using a hard conversion approach, 1 mile would become 2 kilometers and *55* mph would become 90 km/h.

The FHWA encourages the use of hard conversions.

The use of a hard conversion for distance signs has two important advantages:

- Hard conversions result in shorter legends that require less sign space, which promotes a greater use of inexpensive overlays instead of expensive sign panel replacement. Soft conversions that use either fractional distances (for example: 6 1/4 km) or decimal distances (6.3 km) eat up more sign space than a hard conversion (6 km).

- Hard conversions result in sign legends that are easier to read. Also, soft conversions that use decimals can easily be misread if quickly glimpsed by a passing motorist, with 6.3 km being read as 63 km. As the sign becomes old or dirty, the chance of the decimal point becoming obscured increases.

Soft conversions have the obvious advantage of greater accuracy, But that level of accuracy for highway distance signing is, in reality, not that necessary.

- It is often not practical, or possible, to locate signs exactly where we want them. Locational errors made during sign design or installation, the presence of physical obstructions, or the desire to reduce the number of expensive overhead structures by combining signs onto a single overhead unit, often result in distance signs being placed at other than the precise location desired. This is especially true on urban freeways where there are many exits and points of interest that need to be signed, yet only a limited number of sites for anything other than expensive overhead sign installations. In this environment, signs tend to be combined on overhead structures in a manner that clearly places practicality and cost considerations ahead of complete accuracy.

Issue 2: Hard Versus Soft Conversions (Cont.)

The accuracy provided by soft distance conversions is just not needed. The simplicity and cost savings associated with hard conversions is more important. And, as time goes by and large distance signs deteriorate and are replaced, we can have the best of both worlds by relocating most of these signs to their exact distance locations. However, it should be noted that certain safety related signs, such as load limit and clearance signs, may require a level of accuracy that can only be obtained via soft conversions.

For metric conversion we have adopted the following policy regarding rounding on distance signs, a policy which favors simple hard conversions:

- All signs having an actual distance to the item which they refer of 800 or more meters should be rounded to the nearest even kilometer (For example: 800 m is rounded to 1 km, 1.6 km is rounded to 2 km, and 9.3 km is rounded to 9 km).

- All signs having an actual distance to the item which they refer of less than 800 meters should be rounded to the nearest 100 meters (For example: 799 m is rounded to 800 m, 656 m is rounded to 700 m, and 446 m is rounded to 400 m), unless other policies are given by AASHTO or MUTCD.

- Distances displayed on warning signs and associated supplemental signs should be rounded to the nearest 50 m and use the symbol m.

- Decimals, rather than fractions, should be shown in all cases. Decimal points will be oversized to increase visibility, if used.

The use of hard conversions will undoubtedly require the modification of the legal statutes that support speed zoning. For the Interstate system, laws will need to be passed at the federal level enacting the appropriate equivalences. For other roadways, speed studies conducted by the Montana Department of Transportation should be used to established the proper metric speed limit.

Since geometric design is typically based on a design speed that is 5 to 10 mph greater than the posted speed limit, a slight increase in the actual speed limit should not pose a safety risk with regard to geometrics (tapers, curves, etc.).

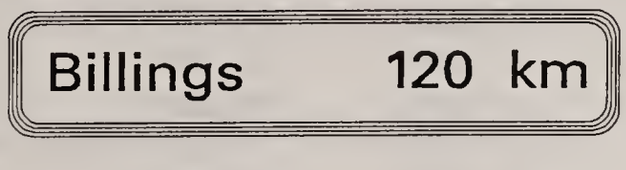
The current AASHTO Task Force on Geometric Design has recommended the adoption of design speeds in 10 km/h increments from 30 km/h thru 120 km/h. The use of even 10 km/h design speed increments is consistent with a hard conversion approach to posted speeds which would allow speed limits to be reasonably set at 10 km/h (6.2 mph) less than the design speed. The MDT will utilize this approach to posting speed limits.

Issue 3: Type of Unit Suffix

In the case of distance signs, the alternatives to be used for distance suffixes are shown below:

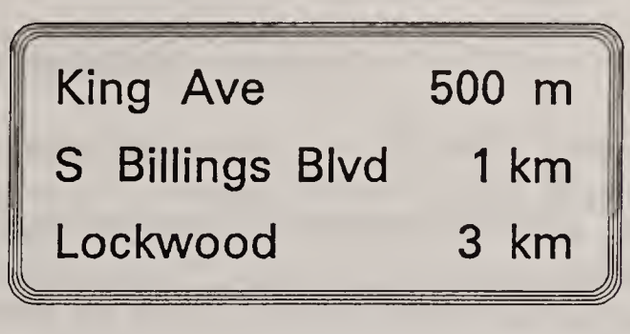
1. **Use of Abbreviated Suffixes (km and m) - In an adjacent arrangement for a permanent installation.**

   For Example:



2. **Use of Mixed Abbreviated Suffixes**

   For Example:



Lower case letters are universally used for metric speed and distance units.

Exclusive use will be made of the abbreviated suffixes in mixed signs. The "m" will always be needed to differentiate distances in meters from distances in kilometers.

Unless it is absolutely necessary to save an expensive sign panel that is otherwise in good condition, avoid the use of supplementary plaques, opting for the adjacent arrangement.

Issue 4: Speed Sign Legends

SPEED LIMIT SIGNS

The following conversion table will indicate what the Department will use in converting Miles Per Hour to Kilometers Per Hour:

25 MPH	-	40 km/h
30 MPH	-	50 km/h
35 MPH	-	60 km/h
40 MPH	-	60 km/h
45 MPH	-	70 km/h
50 MPH	-	80 km/h
55 MPH	-	90 km/h *
65 MPH	-	110 km/h *

* Consistent with Federal and State Laws

In the case of retrofit conversion of existing speed zones, the above table will be sent to the Highway Commission for their review and approval. Upon approval the District Maintenance Offices will be given this conversion table and asked to make the appropriate changes on our maintained routes within their respective areas. The public will be notified of the changes. The Traffic Engineering Section will be available to help the District with any questions that may arise due to the legality of a particular speed zone or the correct placement of the signs. On routes that are not maintained by the MDT the District Personnel should provide this information to the appropriate maintenance jurisdiction.

All of the conversions are in 10 km/h increments and for the most part each of the conversions from MPH to km/h are straight across the board. The only minor differences are with the conversion of 35 mph and 40 mph. They will both go to 60 km/h. Sixty km/h is equal to 37.5 MPH. All new special speed zones will follow existing development procedures. Speed limits will be displayed in 10 km/h increments.

ADVISORY SPEED SIGNS

It is recommended that **advisory** speed signs be posted in increments of 10 km/h, which is consistent with both Canadian and Australian practice:

> "Advisory speeds should be posted in increments of 10 km/h." (Manual for the Operation of Changing Signs to the Metric System, NAASRA, 1972)
>
> "The speed shown [for advisory signs] should be in multiples of 10 km/h." (Uniform Traffic Control Devices for Canada, January 1976)

However, these sign panels should be square with the "km/h" legend provided below the

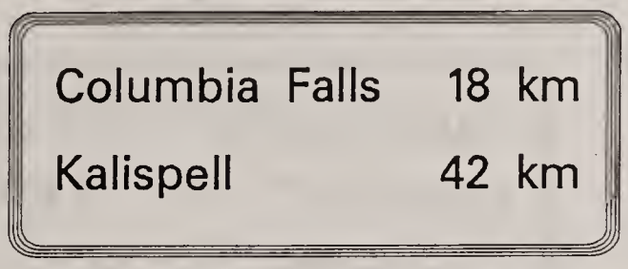
numerals and will not have the red circle around the numerals recommended for the regular speed limit signs.

STANDARD CASES AND SIGN CONVERSION DETAILS

Keeping the design issues discussed in the previous section in mind, included below is a standard set of conversion cases and design details for both distance and speed signs. These items are best illustrated through examples which modify the legends presented previously for each basic sign type:

Destination Signs (without directional arrows)

Convert to:



If possible use partial overlay.

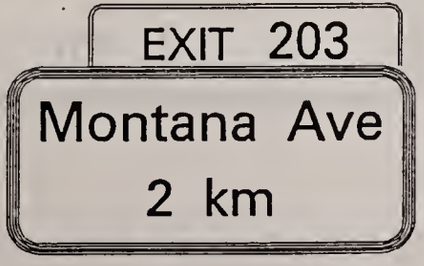
Advance Guide Signs (<u>without</u> exit numbering)

Convert to:

Use partial overlay

Advance Guide Signs (<u>with</u> exit numbering)

Convert to:



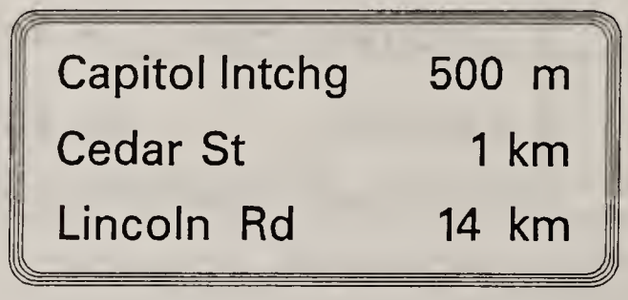
Use partial overlay.

The primary Advance Guide sign should be located a distance of 2 km prior to the exit gore. A preliminary Advance Guide sign at 4 km may also be employed if deemed necessary, such as at major interchanges. In cases where it is not desirable, or possible, to locate the sign at the exact 2 and 4 km points from the interchange, distances should be shown to the nearest kilometer.

Convert all existing Advance Guide Signs with a 1 Mile legend to 2 km and all signs with a 2 Mile legend to 3 km, realizing that a distance discrepancy will occur. If at some point in the future, these signs require replacing then they would be relocated to the exact distance.

Interchange Sequence Signs

Convert to:



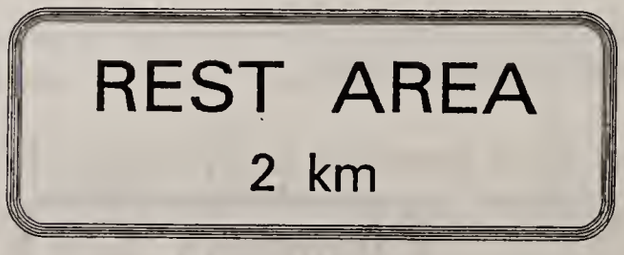
If possible, use partial overlays. If this is not possible, abbreviate or eliminate "Ave", "Blvd", etc. and use a complete overlay.

On urban freeways having less than 2 km between interchanges, the interchange sequence signs should be used in lieu of the advance guide sign for the affected interchanges.

The MUTCD currently provides no quantitative guidance on this issue.

Advance Rest Area/Service Center Sign

Convert to:



Use partial overlay.

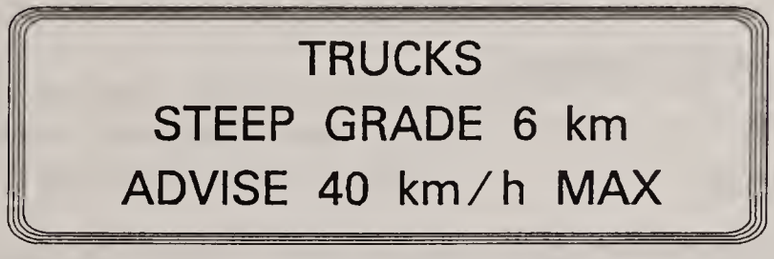
Warning Signs (Diamond-shaped with supplemental plaque)

Convert to:

Use complete supplemental panel replacement.

Or for rectangular shape sign with special message.

Convert to:



Use partial overlay.

Standard Speed Limit Signs

Should conform to MUTCD standards:

Replace entire installation.

STANDARD CASES AND SIGN CONVERSION DETAILS (Cont.)

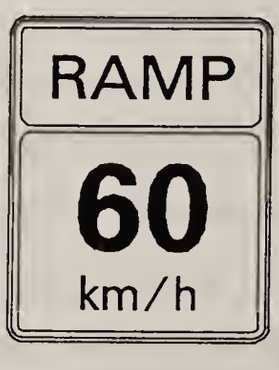
School Speed Limit Signs (ground mounted)

Should conform to MUTCD standards:

Use complete panel replacement.

Ramp/Exit Advisory Speed Signs

Convert To:



Use complete panel replacement.

Advisory Speed Signs

Convert To:

Use complete panel replacement.

MDT will use the sign lay-outs which will be established by the MUTCD.

WORK ZONE SIGNS

In order to provide consistency in distance and speed units on the highways covered in this project, work zone signing shall be converted to metric units. In general, advance work zone signing should be placed at the 2 km, 1 km, and/or 500 m points. Weight, height and width limits will have dual indications for weight and measures.

PUBLIC AWARENESS PLAN

The Public Awareness Plan will be developed by the Public Affairs Unit with review by the impacted sections. The Traffic Engineering Section will notify the Public Affairs Bureau when metric signs will be implemented. (See Chapter 12 for additional information)

RECOMMENDATIONS

Based on the results of our literature search and review, and using a little common sense, the following recommendations are made:

- Use hard conversions to the maximum extent practical for distance and speed signing.
- Signs referencing distances of greater than or equal to 800 meters should be rounded to the nearest whole kilometer. Signs referencing distances of less than 800 meters should be rounded to the nearest 100 meters.
- The suffix "km" should be used for all distances expressed in kilometers and the suffix "m" should be used for all distances expressed in meters. Then conform to the requirements of the MUTCD when made available.
- Unless absolutely necessary, avoid the use of supplemental "km" tabs on separate sign panels located above the distance value. Instead, fabricate a new sign with the "km" suffix included as an integral part of the sign.
- Speed limits should be posted in even increments of 10 kilometers per hour. The federal government should be encouraged to enact appropriate enabling legislation for the interstate system. The new metric speed limits on non-interstate facilities should be established based on recent MDT speed studies and state laws.
- The standard speed limit signing should conform to the MUTCD.

In conclusion, it should be emphasized that, in the area of sign design and construction, the "field of play" is constantly changing as existing signs are replaced or upgraded by maintenance forces. Consequently, prior to commencement of construction and during the construction process, the sign modifications reflected in our final design plans will need to be re-examined to make sure that all proposed changes are still appropriate. A significant amount of field adjustment will undoubtedly be needed.

PAVEMENT MARKINGS

Width in inches x 25 = millimeters

Typical metric widths 100 mm

150 mm

200 mm

Pavement marking lengths in feet x 0.30 = meters.

Typical hop-skip line of 10 feet and 30 feet = 3 m and 9 m.

The difference between a hard and soft conversion is 1.6 percent.

GENERAL PROCESS TOPICS

Contracts

- Stencils and dies will need to be stocked in both metric and English for quite a while, until all of our current signs have been replaced.

Machinery in the Sign Shop

- The machinery that is rated in ton capacity will require adjustments.
- The measuring and calibrating devices attached to existing equipment will require retro-fitted metric scales.

Field Equipment

- The Distance Measuring Instruments (DMI's) used for field inventory have a switch for conversion to kilometers.
- The vehicle odometers, of course, are not as easily changed and since we do a great deal of our work referencing this device, consideration should be given to ordering vehicles with meter-based odometers once our reference system is changed over.
- The radar guns will eventually require modification or replacement.

Signals

- The face size, mast arm length, cabinet dimensions, etc. must be converted along with the entire standard when it is appropriate.

Format and Forms

- Specialized traffic forms and those with outdated units will require modification to accommodate metrication.

Manuals and References

The following manuals and references must be converted to metric units:

Federal Highway Administration
- Manual on Uniform Traffic Control Devices
- Traffic Control Devices Handbook
- Highway Capacity Manual
- Standard Highway Signs

State of Montana
- Montana Code Annotated

American Association of State and Highway Transportation Officials
- AASHTO Guide for Selecting, Locating, and Designing Traffic Barriers
- Roadside Design Guide

Institute of Transportation Engineers
- Traffic Engineering Handbook
- Transportation Planning Handbook

Montana Department of Transportation
- Traffic Manual
- Signs and Signing Materials Catalog and other documents.

Standards and Specifications
- The MDT Standard Specifications for Road and Bridge Construction
- The MDT Standard Drawings

Materials and Supplies

- Scales, measuring tapes, measuring wheels, radar guns, drafting template, sign shop templates and dies must all be replaced with metric equivalents.

Software and Data Files

- The Metric Edition of Standard Alphabets, 1977 will continue to be the national standard for highway sign and pavement marking alphabets. (FHWA Memorandum August 17, 1993)

- Some proprietary and computational software will require replacement. This includes the Highway Capacity Software, and Passer II.

Construction Bureau

- Review and revise Construction Specifications (Traffic Related Items, i.e. a multitude of dimensioning/unit changes will be required. They are too numerous to list here. This effort will require a detailed review of each Traffic related section.)

- Review and revise Construction Procedures (Traffic Related Items, e.g. the construction procedures and requirements are spelled out in the Specifications, Standards, and the Construction Manual and they are scheduled for modification.)

Materials/Maintenance and Equipment Bureaus

- Review and revise the Maintenance Manual, and the Materials Manual. A multitude of dimensioning/unit changes will be required. They are to numerous too list here. This effort will require a detailed review of each Traffic related section.

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CHAPTER SEVEN

Maintenance

The text for this chapter will be added when available.

GRANT BINDER
800 298 5555

CHAPTER EIGHT

Planning

UNITS

Quantity	Unit	Symbol
length	millimeter meter kilometer	mm m km
area	square millimeter square meter	mm^2 m^2
mass	gram kilogram metric ton	g kg t
temperature	degree Celsius	°C

PLANNING

Overall, the planning unit will be reactive to other units.

- Future Transportation Plans must reflect metric units.
- Data requested by the unit must be provided in metric.
- No past plans will be converted to metric.

PAVEMENT MANAGEMENT PROGRAM

- All future software must handle metric units.
- The process of converting measurements such as International Roughness Index (IRI) and rut depth from metric to English units, will be discontinued.

INTERMODAL

- All databases must be established in metric units.
- Any other existing data must be converted by the hard conversion convention.

GIS

- The ARCINFO software will continue to be run with metric units.

TRAFFIC

- Figures the Traffic Section is responsible for will be unaffected by the conversion to metric.

- The database "section termini" must be converted to read "reference point" rather than "milepoint".

FIELD

- The Distance Measuring Instruments (DMI) must be recalibrated to metric, and metric tapes must be purchased for all field personnel.

DATA MANAGEMENT

- The Integrated Roadway System (IRIS) database must be converted to metric with the assistance of Information Systems personnel (this will be mostly technical in nature, as the conversion will nearly be performed as per the hard conversion conventions).

- Records with descriptions indicating state highway mileposts, which will be converted to reference points must be converted to metric.

- New software must be acquired from FHWA so that all reports submitted to them will be in metric units.

The consensus amongst personnel in MDT is that the preferred course of action regarding existing mileposts is that they remain and be converted to reference points. Removing them in favor of kilometer posts would essentially result in recreating all databases to reflect the new kilometer posts. This would create an inordinate amount of work for the GIS, Traffic, Pavement Management and Data Management units, all of which keep their own databases.

CRANE BINDER
800 298 5555

CHAPTER NINE

Environmental

The Environmental & Hazardous Waste Bureau will complete the metrication of the Bureau through the combined efforts of the Section Supervisors and the Metric Coordinator.

Resources & Permitting Section

Cultural Resource Unit

- All field measurements must be recorded in metric units.
- Project site location information must be recorded in measurements reflecting milepost units that comply with MDT policy.
- Distance measurements must be shown in metric with English units in parenthesis.
- Areas must be converted to square meters or hectares with English units in parenthesis.
- Maps, sketches, photographs, and their scales must be shown in metric units.
- Transportation project reports must show both units of measurement and English will be discussed for the general audience. The metric unit must be shown first in these reports with the English units in parenthesis.

Biological Unit

- Field measurements, plans, and maps must be dimensioned in both metric and English units.
- Areas must be converted to square meters or hectares, but will also show English units.
- Stream flows and volumes must be given in metric units with English units in parenthesis.

- Wildlife resource mitigation including fences, crossing structures, lighting, reflector spacing, and boulder size must be dimensioned in metric units along with the English equivalents.

- Units of measurement described in some regulatory documents must be converted to metric units at the time of application and will be discussed in the narrative in metric and English units.

Hazardous Waste Section

Noise Analysis Program

- After March 31, 1994, all field measurements must be in both metric and English units.

- Noise manual tables and graphs must be converted to metric units during future use. This must be done by the Bureau section that is the primary source of these tables and graphs.

- Computer units used to analyze and predict traffic noise levels must accept metric units as well as English units.

- Noise barrier panels should be dimensioned in metric units with English equivalents shown in parenthesis.

- Traffic noise sound levels must be reported in units called "A-weighted decibels" shown as dBA. This unit represents the sound from highway traffic noise "weighted" to reflect noise levels as perceived by the human ear. This unit is used worldwide. Metric units will be used in technical reports or research.

- The Noise Abatement Guidelines must be revised to include metric units. The extent of these changes are limited to approximately four distance-related references. The updating of referenced publications and federal regulations will be the responsibility of the publisher.

Leaking Underground Storage Tank (LUST) Remediation Program

- After March 31, 1994, all field measurements, such as soil excavation, stationing, and drawings, must be in both metric and English units.

- Contaminate levels must be recorded in metric units and expressed in parts per million (ppm) or parts per billion (ppb).

- Detailed Site Investigation forms must be changed to show metric and English units.

- Work Plans must be changed to show metric and English units.

- Computer programs used to compile and analyze storage tank data must accept metric data.

- Spill Prevention, Control and Countermeasure Plans (SPCC) must be changed to show metric and English units.

Air Quality Unit

- Field measurements for line source data (highways, intersections, etc.) must be recorded in metric or converted to metric units and also show English units.

- Data input files for computer programs used to analyze air quality use a mixture of English and metric units. The output/results must be expressed in metric units.

- Air quality information for MDT highway projects must be presented in language that is understandable by the general public.

Hazardous Waste Unit

- Contaminate levels must be measured and reported in metric units. Contaminates in pure water samples must be measured in (ppm) = milligrams per liter, etc. Contaminates in soil or sludge samples must be measured in (ppm) = milligrams per kilogram, etc.

- MDT hazardous waste reporting forms must be revised for metric conversions. Site Assessments must also be revised. Site maps for locations must show a metric and English scale for distances.

- Work Plans must be revised. Work Plans are commonly provided by the consultant doing the work. All Work Plans, as well as maps, field logs, and project narratives must be revised to show metric and English notation. Laboratory results must be given in metric units.

- Hazardous waste issues must be discussed in documents and public meetings in metric units and also English units, as English units are usually more familiar to the audience.

Environmental Engineering Section

Miscellaneous Environmental Services

- The Geographic Information System (GIS) environmental base information must be programmed in metric units. All distance measurements will reflect metric units. This information will be available to MDT staff.

- All project clearances must be reported in metric units.

- Section 4(f) and 6(f) Evaluations must describe impacts to protected resources in metric and English measurements and all maps and photographs must be on metric and English scales.

- Many state agencies that coordinate project activities with us, cooperate in joint agreements, or review our documents will probably not start using metric language until the federally supported state agencies have completed their conversion process. MDT metric conversion decisions and timetables must be communicated to state agencies as early as possible. Also, both English and metric measurements must be shown in technical reports, coordination letters and in environmental documents to reduce the number of problems experienced during the MDT's conversion to the metric system.

- The metric literacy of the public audience must be considered whenever environmental documents are developed and public meetings convened. Both metric and English units must be shown and presented or the conversions are explained at the time the units are discussed.

Coordinating the Conversion Process

- In order to complete the Branch conversion to a metric program, MDT must evaluate the influence of federal agencies that direct our activities, all agencies that coordinate with our activities and those that are influenced by our activities.

- MDT will review the legislation that affects the Bureau operations.

- In the MDT's Environmental & Hazardous Waste Bureau each section supervisor, as well as each environmental specialist, must convert regulatory guidelines and directive material to metric units at the time it is needed and wherever necessary to comply with the MDT objective to convert to metric units.

Training and Internal Coordination

- One general branch training session must be held during the early part of the conversion effort in order to discuss procedures and schedules for completing the metric conversion process.

- Each staff member must be provided a metric conversion table or an electronic conversion option.

- Staff members must become familiar with the metric units used throughout the MDT as they are made available through the MDT Metric Conversion Committee.

- There must be a continued coordination effort throughout the MDT. The OES staff must be aware of the conversion progress in other offices to enable them to assist in completing Department manuals, guides, etc. for which OES shares ownership. Also, it is important to be aware of completed conversions that can be incorporated into OES project development work.

- OES has identified fourteen MDT directives that need either revisions or replacement and metric conversion consideration must be given to each.

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CHAPTER TEN

Computer Systems

This chapter covers all standard programs excluding specialized traffic and bridge programs. The expertise to review those packages is within their respective branches.

The impact of a conversion to metric in our computer applications varies by department. The majority of the systems are already capable of working in metric by setting a default switch in the program set-up. The primary problem will be loading of metric standards tables to replace the existing English tables. This will take some time and needs to be placed in the Department's schedule for conversion.

There are a few problems associated with a conversion to metric:

One problem that we foresee are the R.O.W applications. Actually, the problem is not with the software, rather with the industry standard in providing legal descriptions. It is not certain what influence the Transportation industry will have on the legal and Real Estate businesses.

Neither Hydrain or WSPro programs used by Hydraulics will work in metric. Hydraulics will continue to do calculations in English units and convert to metric until these programs are converted to metric by the FHWA.

The conversion to metric may require us to determine new standards for significant figures in calculations. For example, if linear measurements are kept to the hundredths, the accuracy between feet and meters could be significant. This needs to be explored.

GRAPHICS

Microstation

Microstation is equipped for metric units through it's master unit (MU): sub-unit (SU): positional unit (PU) system. MDT's current file standard is 1:10:1000 (MU:SU:PU), where the master unit is a foot. The new standard MU:SU:PU for metric files will be 1:1000:10, where the master unit is the meter and the sub-unit is the millimeter.

Converting a drawing such as a strip map, from feet to meters will require the following procedure:

1. Set the active scale to 0.304 8.
2. Place a fence around the elements to be converted.
3. Scale the fence contents.
4. Change the MU:SU:PU to 1:1000:10. Put an M in the box for master units and mm in the sub units box.

5. Zoom in and snap to a point that both metric and English coordinates are known. Then set the global origin to the metric coordinates.

   Note: This procedure is for two-dimensional files only and affects only "XY" values. "Z" values must be changed through the graphics file editor.

PLAN SHEET SIZES

CADD plan sheets will continue to be printed on standard 11" x 17", 22" x 34" and 22" x 36" paper until Duplicating Services Unit is able to accommodate the wider metric size paper 11.7" x 16.5". When Duplicating Services has printing presses that can handle the wider paper, we will adopt the international standard plan sizes of A1 - 594 mm x 841 mm (23.4" x 33.1") and A3 - 297 mm x 420 mm (11.7" x 16.5") as standard paper sizes.

Grid size for cross sections will be 1 mm x 1 mm with a bold line at 2 mm x 2 mm spacing.

Plan and profile grid will be 10 mm x 10 mm with bold lines every 20 mm for horizontal stationing.

ENGINEERING

GEOPAK

MDT is still in the initial stage of licensing GEOPAK as a design package, so there are no projects currently being designed that will need to be converted. Training will be developed to perform design work in metric.

IGRDS and RDS

A conversion program to translate foot-based cross-section data into the metric terrain format has been requested and is almost complete.

Existing cogo, horizontal alignments, vertical alignments, templates, slope selection, superelevation, and all other design data must be converted to metric and keypunched into the metric forms.

Some minor fixes on internal fonts and symbols will be required.

Metric design standards will need to be incorporated.

Since no one has designed a complete project with this software, thorough testing of the metric option by Road Design will be necessary to identify all the problems and software bugs.

HYDRAULICS

HEC2 is already equipped for metric data. However, we are not so fortunate with the Hydrain and WSPRO applications. Neither of these programs will operate in the metric environment. They are very dependent on English units. Two solutions are evident for these programs:

- Continue to use them, with hydraulic engineers making soft conversions back and forth. This may be best until the piping industry manufactures everything in metric.

- Purchase new programs that accomplish the same task in metric. In fact, both programs will be changed by FHWA in the end of 1995.

This is an area that will require additional research and effort to determine the best solution.

There are also several programs written in-house that will need modification for metric units.

MANAGEMENT SYSTEMS

A variety of management systems are utilized by the Department. Conversions to metric units will be determined on an individual system basis. Many of the systems depend on input which is unit dependent.

This data also relies on historical information which must either be converted or changed.

This area will need more analysis.

OTHER SYSTEMS

GIS

The current GIS (Geographic Information System) is currently being developed by the Department and is being written to easily convert to metric standards.

HPMS

Pavement Data	Pavement Thickness and IRIs.
Roadway Geometrics	Lane, shoulder, median widths, R/W widths, and passing sight distance.
Other Data	Speed limit, peak capacity, section length.

Note: Conversion will have be coordinated with HIS, Pavement Management, and Traffic systems, as these systems are the source of a great portion of HPMS data. All data is dependent on the mileposts. Some planning will be necessary to determine how to most accurately convert away from milepost-based data.

HIS System

Crashes	Historical databases of accidents. Initial information comes from Highway Patrol.
Structures	Database of all structures locations and conditions.

HIS SYSTEM (Cont.)

Roadway Characteristics	List of traffic volumes, roadway geometry, etc.
Maintainable Items	Uploads of the MMS data used by Maintenance.

All but the structures database are fairly inaccurate. The structures database is based on a greater degree of accuracy, but is still dependent on the mileposts. Some planning will be necessary to determine how to most accurately convert away from milepost-based data.

Construction Bureau

Contractor Estimate System

Contract Plans Section

Average Bid Price System
Contractor Bid Tabulation System

Construction Engineering Application Tools

The Construction Engineering Application Tools represent a system of PC-based application programs written by MDT-ISB staff. These programs are utilized statewide in district, area and headquarters offices. These programs have been maintained and enhanced in accordance with recommendations from users, the Construction Bureau and Road Design Section. The 29 programming functions will all need modification for use in metrically designed jobs. Priority will be determined by user and Construction Bureau needs. Other sources, such as the data-collections systems, are being reviewed to replace some of the functions.

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CHAPTER ELEVEN

Photogrammetry and Survey

The following section of the metric guide has been prepared to aid those involved with Photogrammetry and Survey activities in the use of System International (SI) units. Guidelines hereinafter set forth are based on available metric conversion literature, and trends that outwardly appear will eventually become national standards. These guidelines have been prepared to closely maintain present accuracy standards required by users of this information within the Department of Transportation. Unfortunately it is impossible to foresee all potential applications. Therefore, the Photogrammetry and Survey Section welcomes response from users so revisions and additions can be made and ultimately incorporated into the Survey Manual.

BACKGROUND

The three primary federal agencies involved in the production of survey information for public use are the National Geodetic Survey (NGS) in the Department of Commerce, the U.S. Geological Survey (USGS) in the Department of the Interior, and the Bureau of Land Management (BLM) in the Department of the Interior. A number of records from these agencies and other public agencies will be available in metric compatible formats. It is doubtful that some records such as land records from local courthouses and original survey notes from the BLM will be converted. In these instances, appropriate conversions may be required.

The NGS, which maintains a database of horizontal and vertical survey control points has converted to metric units. The North American Datum (NAD) of 1983 and the North American Vertical Datum (NAVD) of 1988 have recently replaced the older NAD 27 and the National Geodetic Vertical Datum (NGVD) 1929 datums.

The USGS produces topographic maps and digital products which are based upon NAD '27 geodetic coordinates and NGVD '29 elevations. Topographic maps and related digital data are best used for location studies in the preliminary stages of design projects. These maps are, in most cases, not accurate enough for final design and engineering design work.

The BLM is in the process of converting all public land survey/records to a geodetic coordinate database which can be expressed in metric units.

Surveyors and engineers working with these products and maps need to be aware of the datums portrayed on the maps. When performing coordinate transformation, one should proceed with caution as local variations have been discovered.

GPS has proven to be an efficient and useful tool for performing preliminary surveys. The GPS methods yield coordinates in the World Geodetic System (WGS) 1984, which for all practical and engineering purposes is the same as NAD '83 and is expressed in metric units. With technological advancements in GPS equipment and software, the metric-based NAD '83 datum is well-suited and accurate enough to be recommended as the datum to use for resource management and inventory, survey control, engineering projects, Geographic Information Systems, and Land Information Systems well into the twenty-first century.

UNITS

The base unit for distances, heights, and depths is the meter. The meter will be used exclusively for all the Department's survey measurements. This specifically excludes the use of prefixes such as milli or kilo for survey measurements. Use of decimals will need to be consistent with the accuracy to be indicated. For example, survey measurements obtained from an EDM or precise chaining would generally be shown in meters to the third decimal place. In contrast to this, a paced distance would appropriately be shown in meters without any decimal places implying an accuracy to the nearest meter.

Angular measurements will remain unchanged and continue to be measured in degrees, minutes, and seconds. Bearings and azimuths will continue to be used without change. Likewise, geodetic positions (i.e., latitude and longitude) will continue to be expressed in degrees, minutes, and seconds. Decimal degrees may still be used for computational purposes, but final results should be expressed in the degree, minute, and second format.

The square meter, hectare, and square kilometer are the three common units that will be used to express area in SI units. As a general rule, the square meter will replace areas now expressed in acres, and the square kilometer will replace areas now expressed in square miles. If there is a question as to which units are to be used, the Bureau or Section requesting the survey should be consulted.

The fundamental unit for volume is the cubic meter (m^3). Use of the liter will apply to some liquid volumes. Please refer to the appropriate write-up for the specific Bureau or Section for units of volume to be used.

Temperature, for surveying purposes, will be expressed in degrees Celsius. Temperature will primarily be used for chain corrections and atmospheric corrections for EDM measurements.

The SI unit for pressure is the pascal, which is a newton per square meter (N/m^2). However, atmospheric pressure is commonly expressed in several other units, including millimeters of mercury (mmHg), kilopascals (kPa), and millibars (mbar). To maintain compatibility with presently owned equipment, the Department will use either millibars or millimeters of mercury. As a cautionary note, each barometer should be checked for units of

pressure being measured and then the total station should be set to accept the same units. If the parts per million (PPM) is being calculated, units of temperature and pressure need to be consistent with the units required in the equation.

The newton is the SI unit of measurement for tension or force. It is equal to mass times acceleration, thus the newton's base units are $kg \cdot m/s^2$. At the present, tension handles are available in kilograms. Until tension handles are available in newtons, the Montana Department of Transportation will use kilograms for calibration of tapes.

The unit of frequency in SI units is the hertz (cycles per second). Frequencies for most electronic distance measuring equipment will be expressed in megahertz (MHz), as is the present standard.

Grades and slopes now expressed as percents or horizontal to vertical ratios will continue to be expressed in the same manner. The difference will be in the definition, which will now define a 1% grade as 1 meter per 100 meters instead of 1 foot per 100 feet. Similarly, slopes now expressed as 4:1 will be interpreted to mean 4 meters horizontal to 1 meter vertical.

EQUIPMENT

Total stations presently owned by the MDT have the capability of measuring in metric units. Owners manuals should be consulted for the proper settings. The Construction Bureau has ordered and distributed some additional metric survey equipment to the field crews. As a minimum, each crew should have metric compatible instruments, level rods, chains, and measuring tapes. Additional equipment that is highly recommended for each crew to have includes: thermometers, barometers, and tension handles.

EDM's used in control work should be capable of displaying measurements to the nearest 0.001 meters. Preferably, chains used for control work should be directly readable to the nearest 0.001 meters. As a minimum, chains should be incremented to the nearest 0.01 meters, whereby measurements to the 0.001 meters can be confidently estimated. Standard Philadelphia level rods used for control levels should have divisions of meters, 0.1 m, 0.01 m (preferably 0.005 m) and not exceed 4 meters in length. Fiberglass rods used for construction staking should have divisions of 1 m, 0.1 m, and 0.01 m.

There are a number of software packages that are being used for survey calculations throughout the districts. It appears most field crews are using either the survey module for the HP41C series calculators, Survey4.0, or MDT's Engineering Application System for survey calculations. Several subroutines for the HP41C survey module are not metric compatible. Survey4.0 is a metric compatible survey package. As of this date, MDT's Engineering Application System programs are not metric compatible. It is anticipated that programs for a majority of the applications on this system will be replaced with the data collector software in the future. Each district or crew is responsible for checking out the software they are using for compatibility with SI units.

CONVERSION FACTORS

When converting English measurements to SI units, the converted value should be carried to an appropriate number of decimals to maintain the original accuracy implied. Significant digits should not be dropped, nor should an accuracy greater than the original measurement be reflected. For instance, a measurement of 100.01 feet mathematically converted to four decimal places would equal 30.483 0 meters. However, four decimal places implies a greater accuracy than the original measurement, which was to the hundredth of a foot. A hundredth of a foot would correspond to an accuracy of 0.003 m. Therefore, the conversion of 30.483 0 meters should be rounded to either the nearest 0.003 meters or better to the nearest 0.005 meters giving an answer of 30.485 meters.

Most conversions will be made utilizing the international SI foot conversion (1 foot = 0.304 8 meters, exactly).

COORDINATES

One exception to the exclusive use of the SI Foot (1 foot = 0.304 8 m) is some coordinate data received from the Photogrammetry and Survey Section. The electronic survey equipment used by the MDT measures distances in meters and then internally converts the distance to feet using the U.S. Survey Foot (1 foot = 0.304 800 61 m) which is slightly different than the SI Foot.

For all practical purposes, the two are the same with approximately two parts per million difference. Where this causes a problem is when metric coordinates are developed using English survey data.

The Photogrammetry and Survey Section will identify the conversion factor used to produce metric coordinates. The designer shall identify the conversion factor used as a footnote to the coordinate table in the plans.

Stationing, bearing, and section tie calculations using metric coordinates will need to be performed using the appropriate conversion factor. If there is any question as to the appropriate conversion factor, contact the Photogrammetry and Survey Section.

APPLICATIONS FOR MDT SURVEYS

Distance measurements for control work will now be recorded to the third decimal place. This is consistent with the output from EDM's. Some chains can be directly read to the third decimal place of a meter, while others will require estimation for the third place. Less precise measurements, typically measurements recorded to the nearest tenth of a foot, will be recorded to the nearest hundredth of a meter.

Level data presently recorded to the hundredth of a foot will be recorded to the nearest five thousandths of a meter. Similarly, level data now recorded to the tenth of a foot will be recorded to the nearest five hundredths of a meter.

Coordinate values for control information will be expressed to the third decimal place of a meter for northing and easting. Elevation coordinates will be expressed to the nearest one thousandths of a meter (0.001 m).

Highway stationing will change to reflect the 100 meter station. The standard stake out and cross section interval will be 20 meters. Intervals of 5 meters, 10 meters, and 40 meters will also be used on occasion.

The practice of designing and expressing curvature in degrees will be discontinued. In its place the radius definition will be used. Spiral curves will also be designed and calculated from the radius. Curve equations including the degree of curvature will no longer be used. The radius should be displayed and calculated to the nearest 0.001 m.

CARTOGRAPHY

Suggested map replacement scales are included in the attached summary chart. The attached chart also contains standard contour intervals which have been adopted by the Photogrammetry Unit.

Item	Current	Proposed Metric Units	Comments
Stationing			
Designation	170+10.34 (1 sta = 100')	51+84.76 (1 sta = 100 m)	Stationing will be in 100 m increments rounded to the nearest 0.01 m.
Staking and Cross Section Intervals	10' (3.04 m) 25' (7.62 m) 50' (15.24 m) 100' (30.48 m) 100' (30.48 m)	5 m (16.4') 10 m (32.8') 10 m (32.8') 20 m (65.6') 40 m (131.2')	20 m stationing will replace 100 foot stationing as the standard for construction staking, cross sectioning, etc. There will be instances where other stationing intervals will be used. Other intervals to be used will include 5 m, 10 m, and 40 m increments. It is anticipated that non-standard stationing increments will be designated in the preliminary field review report or in the survey request memo.
Angles and Bearings	DMS	DMS	Field angles will be reduced to the nearest second. Angles and bearings on plans will also be designated to nearest second.
Grades	2.105%	2.105%	Grades shown will continue to be shown to the third decimal place.
Coordinate Values			Coordinate values designated to the nearest 0.001 m.
North, East (Y,X)	1522.76	464.138	
Elevation (Z)	1234.12	376.160 (will be either 0 or 5)	MDT BM and control elevations will be designated to the nearest 0.001 m. BM information from other agencies will be designated to the same accuracy as published by that particular agency.
Curve Data	Degree of Curve	Radius Definition	Design of curves and spirals will be based off a radius instead of a degree of curvature, the radius to be designated to the nearest 0.001 m.
Mapping			
Contour Intervals	1' (0.30 m) 2' (0.61 m) None 5' (1.52 m)	0.5 m (1.64') 0.5 m (1.64') 1 m (3.28') 2 m (6.56')	Photogrammetry will replace current contour intervals with the ones herein designated.
Map Scales	full size half size 2"=1' (1:6) 1"=1' (1:12) 1"=2' (1:24) 1"=5' (1:60) 1"=10' (1:120) 1"=20' (1:240) 1"=30' (1:360) 1"=40' (1:480) 1"=50' (1:600) 1"=100' (1:1200)	1:1 1:2* 1:5 1:10 1:20 1:50 1:100 1:250* 1:500 1:500 1:1000 1:1000	Mapping scales and proposed replacement scales. * Denotes limited usage scales.

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CHAPTER TWELVE

Public Affairs

So that the public is not caught by surprise when the metric conversion takes place, a public awareness campaign will be undertaken. The following campaign elements are recommended:

SIGNING

- Install Metric Equivalence signs on all major entrances into Montana, adding an overlay which reads:

  METRIC SIGNING CHANGES BEGIN IN (Month/yr.)

- Prepare radio and television spots for broadcasts one month prior to the beginning of sign conversion and continuing two months after the completion of the sign conversion.

- Install Highway Advisory Radio signs

  TUNE RADIO TO ___ AM FOR METRIC SIGN UPDATES

  at the major entrances to Montana and coordinate with the Montana Department of Commerce. These broadcasts will be used to provide greater detail on the metric conversion system.

- Consider the installation of single-post signs at the on ramps to the major grade-separated facilities. These signs would read:

  METRIC SIGNS IN USE

- Make use of permanent Variable Message Sign systems to provide metric information to motorists.

- Contact the 3M Company concerning their free billboard advertising program to see if it would apply to this public project.

- Inform the America Automobile Association (AAA) and the American Trucking Association (ATA) of the changes so they can alert their members.

The public awareness plan will be developed by the Public Affairs Bureau in cooperation with the Traffic Engineering Section.

RIGHT-OF-WAY

Handouts will need to be developed in cooperation with the Right-of-Way Bureau for distribution to landowners compensated or any interested person. The handouts should explain the metric system and graphically show the difference between the English and metric systems.

ADDITIONAL ITEMS

Additional items will require coordination with the appropriate MDT Sections and Bureaus. The cities, counties and other state and federal agencies may also become involved and the Public Affairs Bureau will coordinate with those entities on a case-by-case basis.

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CHAPTER THIRTEEN

Motor Carrier Services Division

Due to the interstate nature of the trucking industry, the Motor Carrier Services (MCS) Division Conversion Plan will be as follows:

- Coordinate with other states in the region so that the switch over to metrics occurs uniformly from state-to-state including Montana.
- Publish a Metric Conversion Handbook for the trucking industry with distribution by June 1, 1995.
- Provide training for MCS employees regarding metrication.
- Switch over MCS weigh station equipment to metrics in coordination with surrounding states.

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GENERAL REFERENCES

The following references were used in preparation of this manual and/or are available as aids to metric conversion.

METRIC CONSTRUCTION GUIDES

American Society for Testing and Materials (1916 Race Street, Philadelphia, PA 19103, Phone: (215)299-5585):

- *ASTM E621, Standard Practice for the Use of Metric (SI) Units in Building Design and Construction, 1984,* 37 pp., 1984, $12.00.

National Institute of Building Sciences (Publications Department, 1201 L Street N.W., Suite 400, Washington, CD 20005, Phone: (202)289-7800):

- *The Metric Guide for Federal Construction,* 1st Edition, Operating Committee of the Interagency Council on Metric Policy, National Institute of Building Sciences (NIBS), Washington, DC, 1991. Written by NIBS specifically for the construction industry and reviewed by metric experts throughout the country. Includes background on the federal metric laws; facts on metric in construction; an introduction to metric units; a primer on metric usage for architects, engineers, and the trades; requirements for metric drawings and specifications; guidance on metric management and training; and a list of current metric construction references. 34 pp., $15.00 (including shipping and handling).

- *GSA Metric Design Guide.* Interim design guide developed by the General Services Administration (GSA) for use by federal project managers and their A/Es. Contains practical architectural, civil, structural, mechanical, and electrical design information; a list of available "hard" metric products; sample drawings; and related reference information. 77 pp., $8.00; $5.00 if ordered with the above *Metric Guide for Federal Construction.*

National Technical Information Service (5285 Port Royal Rd., Springfield, VA 22161, Phone: (703)487-4600).

- NBS Technical Note 990, *The Selection of Preferred Metric Values for Design and Construction.* H.J. Milton, author, 75 pp.

GENERAL METRIC INFORMATION

American Association of State and Highway Transportation Officials (444 N. Capital St., N.W., Suite 225, Washington, DC 20001; Phone (202)624-5800):

- *Guide to Metric Conversion.*

American National Metric Council (Washington, DC; Phone (410)727-0882 for publications):

- *ANMC Metric Editorial Guide*, $5.00.
- *SI Metric Training Guide*, $5.00.
- *Metrication for the Manager*, $15.00.

National Technical Information Service (5285 Port Royal Rd., Springfield, VA 22161; Phone: (703)487-4600):

- PB 89-226922, *Metric Handbook for Federal Officials* (includes Federal Standard No. 376A of May 5, 1983, *Preferred Metric Units General Use by the Federal Government*), 45 pp., 1989, $17.00.

U.S. Government Printing Office (Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402; Phone: (202)783-3238):

- NIST Special Publication 33, 1991 Edition, *The International System of Units (SI)*, 56 pp., August, 1991, $3.50.
- NIST Special Publication 811, *Guide for the Use of International System of Units*, Arthur O. McCoubrey, author, 34 pp., September, 1991, $2.50.
- "Metric System of Measurement: Interpretation of the International System of Units for the United States: Notice, *Federal Register*, December 20, 1990.

U.S. Metric Association (10245 Andasol Ave., Northridge, CA 91325; Phone: (818)363-5606):

- *Style Guide to the Use of the Metric System*, $3.00; bulk discounts available.
- *SI Metric Style Guide for Written and Computer Usage*, $2.00; bulk discounts available.
- *Freeman Training/Education Metric Materials List*, $38.00.
- *Metric Vendor List*, $28.00.

STANDARDS & SPECIFICATIONS

American Association of State and Highway Transportation Officials (444 N. Capital St., N.W., Suite 225, Washington, DC 20001; Phone (202)624-5800):

- *Standard Specifications for Transportation Materials*. Two-volume set, includes dual units, $115.00.

- *A Policy on Geometric Design of Highway and Streets*, 1990.

    - *Interim Selected Metric Values for Geometric Design*.

American National Standards Institute, Inc. (11 West 42nd St., New York, NY 10036; Phone: (212)642-4900):

- ANSI/IEEE 268, *American National Standard Metric Practice*, 48 pp., 1982, $23.00.

American Society for Testing and Materials (1916 Race St., Philadelphia, PA 19103; Phone: (215)299-5585):

- ASTM E380, *Standard Practice for Use of the International System of Units (SI)*, 35 pp., 1992, $23.00.

CIVIL

American Congress on Surveying and Mapping (5411 Grosvenor Lane, Suite 100, Bethesda, MD 20814; Phone (301)493-0200):

- *Metric Practice Guide for Surveying and Mapping*, 11 pp., 1978, $10.00.

American National Metric Council (1735 N. Lynn St., Suite 950, Arlington, VA 22209; Phone: (703)524-2007):

- *ANMC Metric Editorial Guide*, Fourth edition, 16 pp., 1990, $2.00.

- *SI Metric Training Guide*, 17 pp., 1991.

- *Managing Metrication in Business and Industry*, 203 pp., 1976.

STANDARDS & SPECIFICATIONS (MDT)

Montana Department of Transportation (2701 Prospect Avenue, P.O. Box 201001, Helena, MT 5962-1001):

- *Standard Specifications for Road and Bridge Construction*, 667 pp., 1987 edition (includes Supplemental Specifications).
- *MDT Materials Manual*, published and updated by the MDT Materials Bureau.
- *MDT Survey Manual*, published and updated through the Construction Bureau and Photogrammetry and Survey Section.

STEEL

American Institute of Steel Construction (Metric Publications, One E. Wacker Dr., Suite 3100, Chicago, IL 60601-2001; Phone: (312)670-5414):

- *Metric Properties of Structural Shapes with Dimensions According to ASTM A6M*, Metric version of Part I of the *Manual of Steel Construction*, $10.00.
- *Manual of Steel Construction, Metric Edition*, to be published in 1994.
- *Load and Resistance Factor Design*, 1986.

Industrial Fasteners Institute (1105 East Ohio Building, 171 E. 9th St., Cleveland, OH 44114; Phone: (216)241-1482):

- *Metric Fastener Standards*, $60.00.

STRUCTURES

Florida Wire and Cable Company (P.O. Box 6835, Jacksonville, FL 32236, Phone: (800)874-0093):

- *Physical Properties of Strand, Uncoated, Stress Relieved for Prestressed Concrete Structures.*

Ralph E. Anderson, Chief of Bridges and Structures, Illinois Department of Transportation:

- *Memorandum on Metric Conversions*, March 1, 1993.

American Association of State Highway and Transportation Officials (444 N. Capital St., N.W., Suite 225, Washington, DC 20001; Phone (202)624-5800):

- *Standard Specifications for Highway Bridges*, 1992, with interim 1993.

MEASURING INSTRUMENTS

Stanley Tools (800)262-2161, **Lufkin** (912)362-7511, or **U.S. Tape** (703)256-1500:

- *Dual Unit Tape Measures.*

Staedtler-Mars (Model 987-18-1), **Alvin** (Model 117 PM), and **Charvoz** (Model 30-1261):

- *Metric Scales and Templates.*

American Standard (Call Ms. Barbara Munson at (703)841-9585):

- *Metric Plumbing Templates.*

Sharp Instrument Company (Van Schaack Premium Group, 4747 W. Peterson, Chicago, IL 60646; Phone: (312)736-5600):

- *Sharp Model EL-344G Metric Calculator*, converts linear dimensions, areas, volumes, liquids, pressures, and masses with two keystrokes. Very handy for simple conversions. Under $20.00.

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